Energy Consumption Pattern and Scope for Energy Conservation in Passenger Vehicles in Road Transportation in Kolkata and in Selected Regions of West Bengal

THESIS SUBMITTED FOR THE DEGREE OF
DOCTOR OF PHILOSOPHY (ENGINEERING)

BY

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2022

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INDEX NO. **D-7 / ISLM/5/15**

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ii) **Study on possible economic and environmental impacts of electric vehicle infrastructure in public road transport in Kolkata,** Clean Technologies and Environmental Policy; 2015; 17; 1093-1101

iii) **Studies on Energy Consumption Pattern in Mechanized Van Rickshaws in West Bengal and the Problems Associated with these Vehicles,** Energy Procedia, 2014; 54; 111-115

Book Chapter

i) **Variation in fuel consumption with load in private cars – scenario in real-time traffic conditions, 2021.** Advances in Water Resources Management for Sustainable Use. Lecture Notes in Civil Engineering. 131, 481-494

4. List of Patents: Nil

5. List of Presentations in National / International Conferences:

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CERTIFICATE FROM THE SUPERVISOR

This is to certify that the thesis entitled "**Energy Consumption Pattern and Scope for Energy Conservation in Passenger Vehicles in Road Transportation in Kolkata and in Selected Regions of West Bengal**", submitted by **Mr. Atanu Dutta**, who got his name registered on 22.01.2015 for the award of **Ph.D. (Engineering)** degree of **Jadavpur University**, is absolutely based upon his own work under the supervision of **Prof. Tushar Jash**, Professor, School of Energy Studies, Jadavpur University, and that neither his thesis nor any part of the thesis has been submitted for any degree / diploma or any other academic award anywhere before.

Tushar Jash 30.12.2022

Prof. Tushar Jash

STATEMENT OF ORIGINALITY

I, **Atanu Dutta**, registered on **22.01.2015**, do hereby declare that the thesis entitled **"Energy Consumption Pattern and Scope for Energy Conservation in Passenger Vehicles in Road Transportation in Kolkata and in Selected Regions of West Bengal"**, contains literature survey and original research work done by the undersigned candidate as part of Doctoral studies.

All information in this thesis have been obtained and presented in accordance with existing rules and ethical conduct. I declare that, as required by these rules and conduct, I have fully cited and referred all materials and results that are not original to this work.

I also declare that I have checked this thesis as per the "Policy on Anti Plagiarism, Jadavpur University, 2019", and the level of similarity as checked by iThenticate software is 6%.

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ACKNOWLEDGEMENT

The present work would not have been possible without the inspiration and kind support from many people whom I know and in whatever way I would acknowledge them for their support, it would fall short of what they actually mean to me.

I would like to express my deepest gratitude to my respected supervisor **Prof. Tushar Jash** (Professor, School of Energy Studies, Jadavpur University) for his continuous support and judicious guidance during this research. His diligent motivation helped in the successful completion of my work.

I would like to show my heartiest gratitude to my **Parents** and my **Wife** for their constant motivation for completing this research work, without their support this project would not have been a reality.

I would also like to acknowledge **Prof. Ratan Mandal** (Professor, School of Energy Studies, Jadavpur University) and **Prof. Subhasis Neogi** (retired Professor, School of Energy Studies, Jadavpur University) for showing me the right directions during the difficult times while executing this work.

I am also very much thankful to my respected seniors and fellow scholars **Mr. Deepanjan Majumdar, Mr. Bijoy K. Majhi, Mr. Tarak Nath Chell**, and my friends for actively and constantly supporting me during the complete research tenure. I would also like to express my thanks to the non-teaching staffs of School of Energy Studies, Jadavpur University, for the support during this present research.

Date: 30.12.2022
Place: Kolkata

Atanu Dutta

Atanu Dutta

Dedicated to

my Parents,

(Haridas Datta & Bani Dutta)

my Wife

(Priyanka Das)

&

my Daughter

(Ayantika Dutta)

CONTENTS

Abbreviations

Symbols	Meanings
2W	Two Wheelers
3W	Three Wheelers
4W	Four Wheelers
6W	Six Wheelers
9m	Bus with overall length (over body excluding bumper) 9000 mm with tolerance of ±400 mm
12m	Bus with overall length (over body excluding bumper) 12000 mm with tolerance of -100mm
µC	Microcontroller
A_{max}	Maximum positive acceleration
A_{avg}	Average positive acceleration
A_{rms}	Root Mean Square (RMS) acceleration
AAGR	Average Aannual Growth Rate
AC	Air Conditioned
AGQs	Air Quality Guidelines
ARAI	Automotive Research Association of India
ARDL	Autoregressive Distributed Lag
ARM	Administrative Rules and regulation Management
ATI	Additional Tax Increase
AVL	Advanced Vehicle Location

BAU	Business As Usual
BER	Benefit Expenditure Ratio
BEVs	Battery Electric Vehicles
BI	British Towed Fifth Wheel Bump Integrator
BIO	Biodiesel Vehicles
BRT	Bus Rapid Transit
BRTS	Bus Rapid Transit System
BS-IV	Bharat Stage IV
BUPTCM	Beijing urban passenger transport carbon model
CAGR	Compound Annual Growth Rate
CAPEX	Capital Expenditure
CC	Candidate Cycle
CDM	Clean Development Mechanism
CESC	Calcutta Electric Supply Corporation
CF	Certificate of Fitness
CH_4	Methane
CNG	Compressed Natural Gas
CO	Carbon Monoxide
CO_2	Carbon Dioxide
CP	Comprehensive Policy
CPCB	Central Pollution Control Board

CRR scenario	Comprehensive Scenario
D_{avg}	Average deceleration
D_{DC}	DC duration (min)
DBDC	Delhi Bus Driving Cycle
D_{max}	Maximum deceleration
e3Ws	Electric 3 Wheelers
e4Ws	Electric 4 Wheelers
E_{mean}	Mean Error
E_{cum}	Cumulative Error
EBEC	Electric Bus Energy Consumption
e-BRTS	Electric Bus Rapid Transit System
eBus	Electric Bus
eCars	Electric Cars
EEI	Energy Efficiency Improvement
EU	European Union
EVs	Electric Vehicles
FAME	Faster Adoption and Manufacturing of Hybrid & Electric Vehicles
FB	Fuel Based
FC	Fuel consumption (l)
FC_{DC}	Fuel consumption from DC data
FC_m	Fuel Consumption at motion

FC_{idling}	Fuel consumption at idling (l/km)
FCR_i	Fuel consumption rate at idling (ml/10 min)
FTP	Federal Test Procedure
GCC	Gross Cost Contract
GDP	Gross Domestic Product
GHG	Green House Gas
GPS	Global Positioning System
GTP	Green Transportation Projects
HC	Hydro Carbon
HEL	High Engine Load
HEV	Hybrid Electric Vehicles
ICE	Internal Combustion Engine
IDC	Indian Driving Cycle
IPT	Intermediate Public Transport
K4WDC	Kolkata Four Wheeler Driving Cycle
KBDC	Kolkata Bus Driving Cycle
KE_{n+}	Net positive kinetic energy
KEBDC	Kolkata Electric Bus Driving Cycle
kNN	k Nearest Neighbor
LEAP	Long-range Energy Alternatives Planning
LEL	Low Engine Load
LPG	Liquefied Petroleum Gas

LNG	Liquefied Natural Gas
MAE	Mean Absolute Error
MAPE	Mean Absolute Percentage Error
MC-MC	Markov chain Monte Carlo
MIDC	Modified Indian Driving Cycle
MT	Microtrip
Mtoe	Million Tonnes Oil Equivalent
MUV	Multi Utility Vehicle
N_s	Number of stops per km
NAAQS	National Ambient Air Quality Standards
NBSTC	North Bengal State Transport Corporation
NEDC	New European Driving Cycle
NEMMP	National Electric Mobility Mission Plan
NGV	Natural Gas Vehicles
NMT	Non Motorized Transport
NMVOC	Non-Methane Volatile Organic Compounds
Non AC	Non Air Conditioned
NO_x	Oxides of Nitrogen
NTKM	Net Tonne Kilometers
OBD	On Board Diagnostics
OBDC	Overall Bus Driving Cycle

OPEX	Operational Expenditure
Pb	Lead
PDPT	Priority to Development of Public Transport
PEMS	Portable Emission Measuring System
PEV	Promoting Electric Vehicle
PKE	Positive Kinetic Energy
PKM	Passenger Kilometers
PM	Particulate Matter
PPP	Public Private Partnership
PUC	Pollution Under Control
REF scenario	Reference Scenario
RF	Random Forest
RMSE	Root Mean Square Error
RPM	Respirable Particulate matter
S_{DC}	DC Distance (km)
SAPD	Speed Acceleration Probability Distribution
SBCA	Social Benefit Cost Analysis
SD	Secure Digital
SO_2	Sulphur dioxide
SOC	Sate of Charge
SPM	Suspended Particulate Matter

SPV	Solar Photo Voltaic
SRTU	State Road Transport Undertaking
TCO	Total Cost of Ownership
TDM	Travel Demand Management
T_a	Percentage time in acceleration mode
T_c	Percentage time in cruising mode
T_{cr}	Percentage time in creeping mode
T_d	Percentage time in deceleration mode
T_i	Percentage idling time (%)
T_{idling}	Idling time for trip (min)
TKM	Tonne km
TMOTEC	Transportation Mode-Technology-Energy-CO_2
TP	Technical Progress
TTW	Tank-To-Wheel
V_{avg}	Average speed
$V_{m_{avg}}$	Average moving speed
V_{max}	Maximum Speed
VI	Vulnerability Index
VKT	Vehicle Kilometers Travelled
WBTC	West Bengal Transport Corporation
WHO	World Health Organization

WLTC	World Harmonized Light Vehicle Test Cycle
WTW	Well-To-Wheel

List of Figures

List of Tables

Chapter 1

Introduction

1.1 Introduction:

Energy is the key ingredient for the advancement of any developing nation. Every aspect of life involves the utilization of energy in one form or other. Energy is extracted from various resources such as petroleum oil, natural gas, coal, nuclear power, hydro power, renewable, etc. Until lately, people were least concerned about the fact that conventional energy sources are limited and depleting at a very fast rate. Fortunately, the scenario is changing. Depleting fuel resources and changing climate have made it imperative to focus on efficient mode of utilization of energy, alongside making transition to alternative energy mode, a sine qua non for the present world. More and more people are becoming aware of the situation. More studies and researches are being carried out in the fields of energy conservation, alternative energy sources and renewable energy.

Transport sector plays a major role in the socio-economic development of a particular region. However, as the process of development continues, their side effect gradually becomes more clear and evident. Transportation is reported to be one of the significant energy intensive sectors globally, amounting to an annual contribution of 8% of the global CO_2 emission, as of 2021 (iea.org), which is about 7.7 Gt of CO_2. Apart from the rising concerns of climate issues, the ultimate dependence on crude oil for the major transportation activities, makes it a point of focus for realizing the goal towards energy security and net zero emission targets. Moreover, the emission characteristics from the road transport sector, caused by the internal combustion engine (ICE) vehicles is unique, due to its line type emission characteristics, limiting the control strategies unlike that in case of static emitters like industrial units.

In India, road transport accounts for a substantial portion of emission contribution due to its high dependency of fossil fuels. It accounts for 60% and 80% of the total freight and passenger load in the country (Majumdar et al. 2015). The road transport sector is reported to consume 90% of the high speed diesel among the final commercial form of energy, and the trend is still increasing. The rising demand of the fossil fuel in the form of crude acts as financial burden for the country since 80% of the crude requirement is still imported (Majumdar et al. 2015). This acts as major threat to India’s economy too, being directly impacted by the global geopolitical issues (thewire.in). Moreover, the rising crude oil price volatility imparts majorly increasing the country’s fiscal deficit (hindustamtimes.com).

1.2 Background: Energy Scenario

During the period 2010 to 2019, the world wide primary energy consumption has increased from 505.38 exajoules to 581.51 exajoules which depicts a growth rate of 1.9% per annum (Statistical Review of World Energy 2021).However in 2020, the world witnessed the havoc caused by pandemic COVID-19. As a result the primary energy consumption decreased by 4.5% for the first time since 2009 (Statistical Review of World Energy 2021). The oil consumption decreased by 9.7% (Statistical Review of World Energy 2021). However contribution of renewable and hydro increased by 9.7% and 1% respectively (Statistical Review of World Energy 2021). Oil (31.2%) holds the largest share of energy mix followed by coal (27.2%) (Statistical Review of World Energy 2021). The share of natural gas, renewable, nuclear and hydro in energy mix is 24.7%, 5.7%, 4.3% and 6.9% respectively. The world wide per-capita energy consumption in 2020 was recorded to be 71.5 gigajoules, a 5.5% decline from its previous year data, which otherwise grew at 0.7% per annum till 2019.

India being a developing country, with a total area of 3287263 square km (wikipedia.org) and having a population of 1.38 billion (datacommons.org) as recorded on 2020, has a huge energy demand. Figure 1.1 shows the primary energy consumption trend in India over the past few years. The total primary energy consumption of India in 2019 was 33.89 exajoules and in 2020 was 31.98 exajoules (Statistical Review of World Energy 2021). Till 2019 the primary energy consumption in India grew at a rate of 4.7% annually. However the consumption dipped in 2020 due to countrywide lockdown enforced to mitigate the COVID-19 outbreak situation. Figure 1.2 shows the contribution of different fuels in total primary energy consumption in 2020. It can be observed that coal alone contributed to 54.84% of total primary energy consumption followed by oil with a contribution of 28.19% and natural gas with a contribution of 6.72%. Nuclear energy with a share of 1.25% was the least contributor in the energy consumption scenario. The per capita consumption of primary energy in the same year was reported to be 23.2 gigajoules (Statistical Review of World Energy 2021). A brief overview of the primary energy sources have been discussed in the following sub-sections.

1.2.1 Coal:

Total proved reserves of coal at the end of 2020 was reported to be 111052 million tonnes out of which 105979 million tonnes were anthracite and bituminous coal, and 5073 million tonnes were sub bituminous and lignite coal (Statistical Review of World Energy 2021). Indian coal reserves accounted for 10.3% of total world coal reserve (Statistical Review of World Energy 2021). The production, consumption and import of coal from 2010 to 2020 have been shown in Figures 1.3, 1.4 and 1.5 respectively.

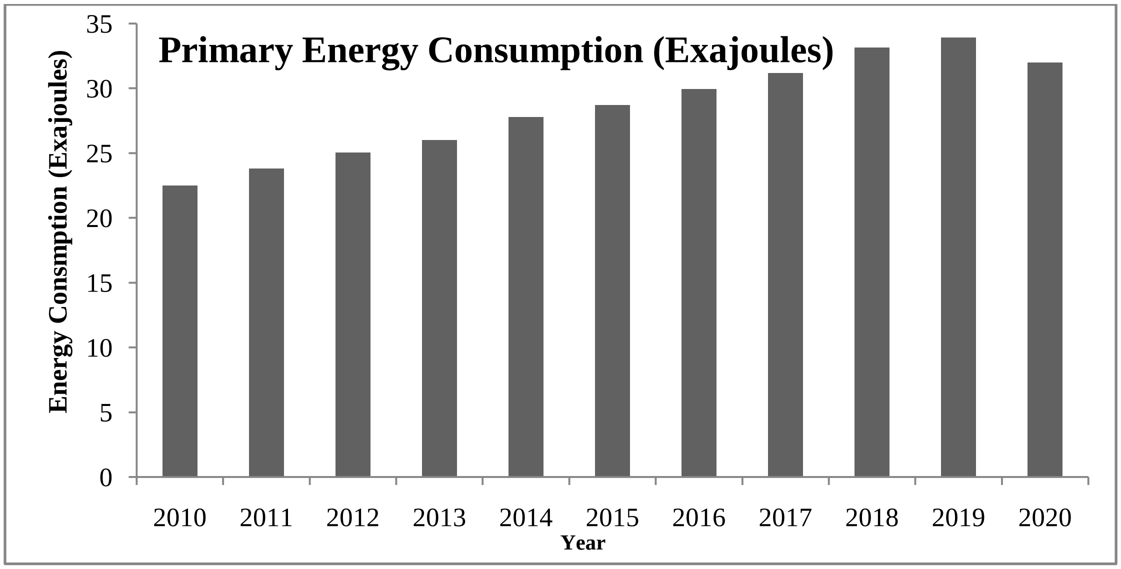


Figure 1.1: Energy consumption trend in India, 2010 - 2020

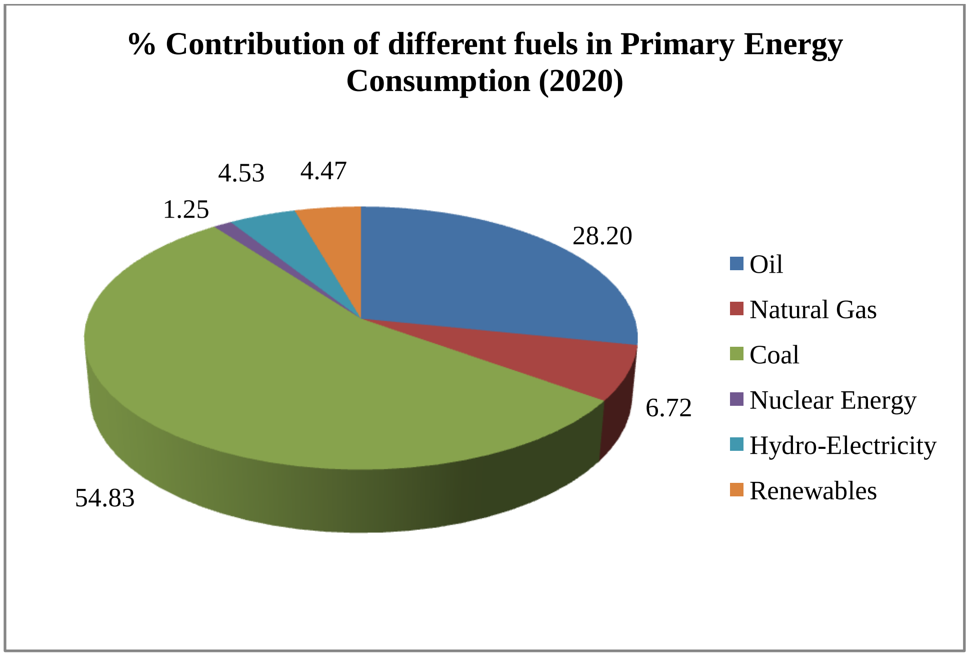


Figure 1.2: Contribution of different fuels in total primary energy consumption in India, 2020

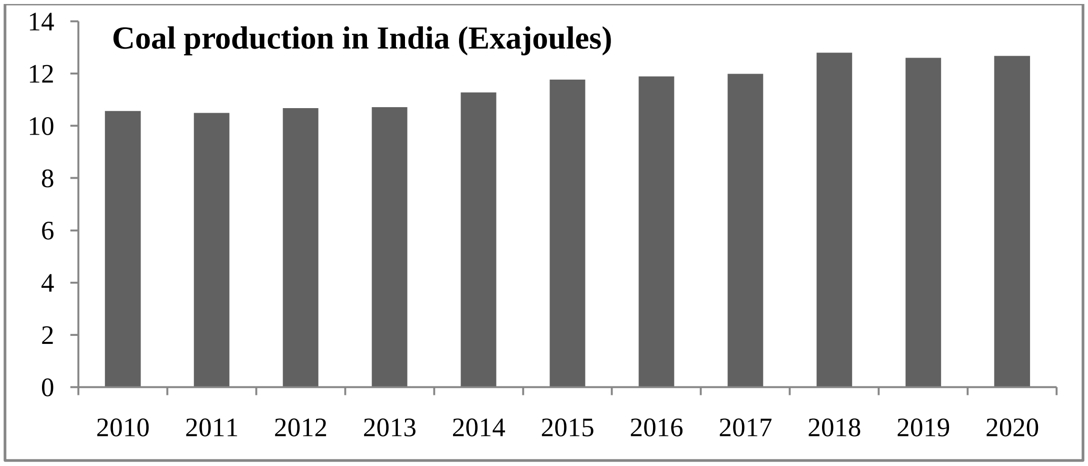


Figure 1.3: Coal production in India (Exajoules)

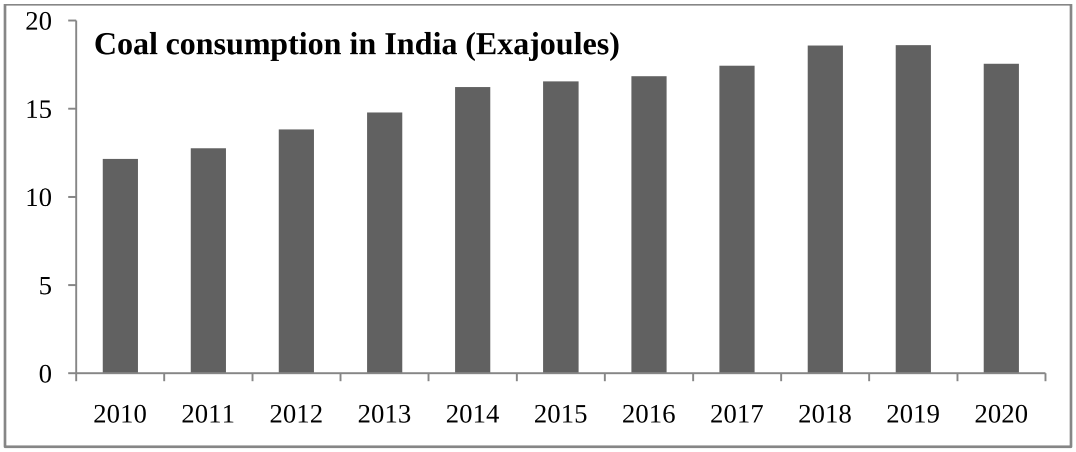


Figure 1.4: Coal consumption in India (Exajoules)

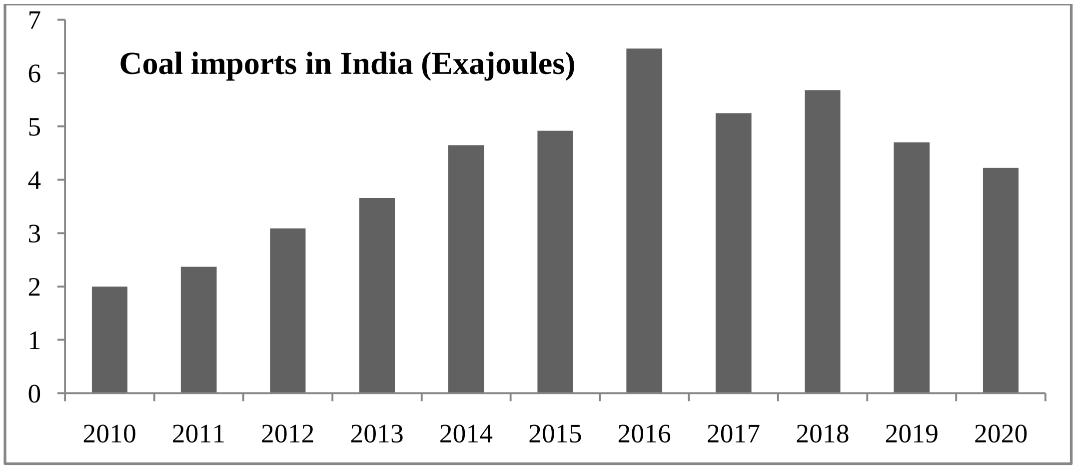


Figure 1.5: Coal imports in India (Exajoules)

It may be observed that during 2009 to 2019, coal production grew at a rate of 2% per annum whereas coal consumption grew at a rate of 4.7% per annum (Statistical Review of World Energy 2021). In the same duration, coal imports grew at a rate of 10.1% (Statistical Review of World Energy 2021).

1.2.2 Petroleum Oil:

Total proved reserves of oil in India at the end of 2020 was reported to be 4.5 thousand million barrels or 0.6 thousand million tonnes (Statistical Review of World Energy 2021). Oil production in 2020 was reported to be 771 thousand barrels per day whereas oil consumption was reported to be 4669 thousand barrels per day (Statistical Review of World Energy 2021). Figure 1.6 shows category wise consumption of oil in India over the past few years. It was reported that consumption of gasoline that grew at 9.1% per anum during 2009 and 2019, dropped by 11% in 2020, and consumption of diesel or gasoil that grew at 4.3% per anum during 2009 and 2019, dropped by 14.5% in 2020 (Statistical Review of World Energy 2021). It is evident from the data that oil consumption is much higher as compared to production and consequently India has to depend on imported oil largely. Figure 1.7 shows the oil import trend over the past decade. The oil imports grew at a rate of 4.4% from 2009 to 2019 (Statistical Review of World Energy 2021). In 2020 India imported 5030 thousand barrels of oil per day (6.7% less as compared to 2019) out of which crude imports and product imports were 4084 and 946 thousand barrels per day respectively (Statistical Review of World Energy 2021).

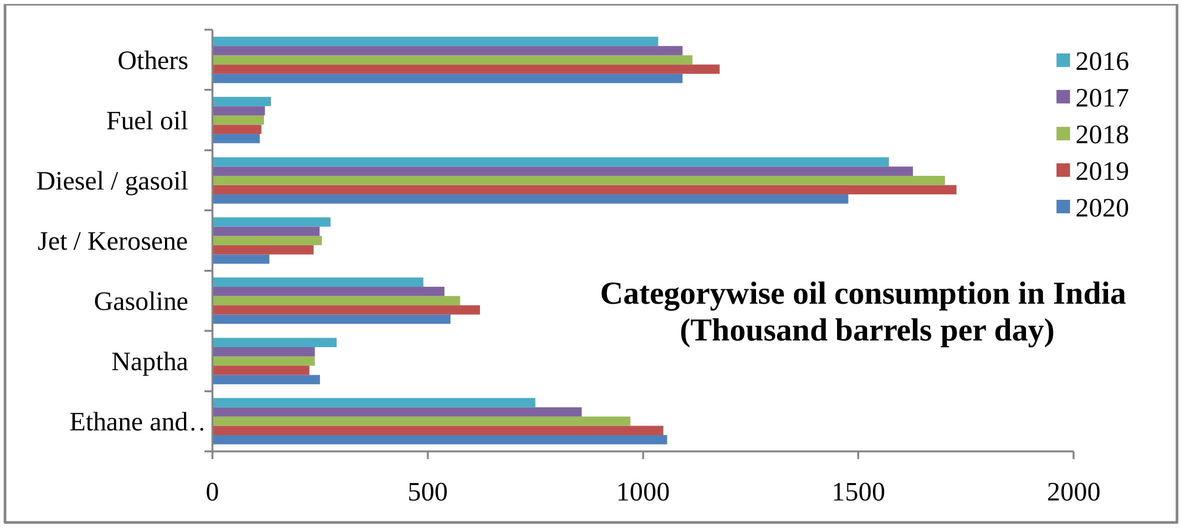


Figure 1.6: Categorywise oil consumption in India

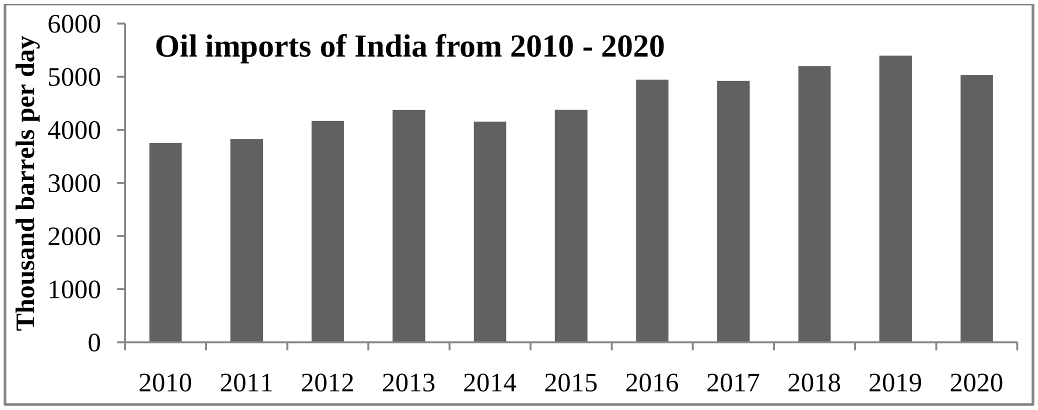


Figure 1.7: Oil imports of India from 2010 - 2020

1.2.3 Natural Gas:

Total proved reserves of natural gas in India at the end of 2020 was reported to be 1.3 trillion cubic meters (Statistical Review of World Energy 2021). Figure 1.8, 1.9 and 1.10 shows the trend in production, consumption and import of natural gas respectively from 2010 to 2020. It can be clearly observed from the figure that although the production of natural gas has decreased over the years, the consumption has increased in the recent past, and along with it the imports have also increased. Data suggests that production of natural gas has decreased at a rate of 2.9% per annum during the period 2010 to 2019 and in 2020 the production was recorded to be 23.8 billion cubic meters (Statistical Review of World Energy 2021). On the contrary, natural gas consumption grew at a rate of 1.9% per annum from 2010 to 2019, and in 2020 the consumption was recorded to be 59.6 billion cubic meters (Statistical Review of World Energy 2021). In accordance with the consumption, the imports of Liquefied Natural Gas (LNG) grew at a rate of 9.6% from 2009 to 2019, and the year 2020 recorded the import of 35.8 billion cubic meters of LNG (Statistical Review of World Energy 2021).

1.2.4 Nuclear Energy and Hydroelectricity:

Figure 1.11 shows that nuclear energy consumption in India has increased from 0.22 exajoules in 2010 to 0.40 exajoules in 2019 at a growth rate of 9.7% per annum (Statistical Review of World Energy 2021). Also, from Figure 1.12 it may be observed that hydroelectricity consumption in India has increased from 1.02 exajoules in 2010 to 1.44 exajoules in 2019 at a growth rate of 3.7% per annum (Statistical Review of World Energy 2021).

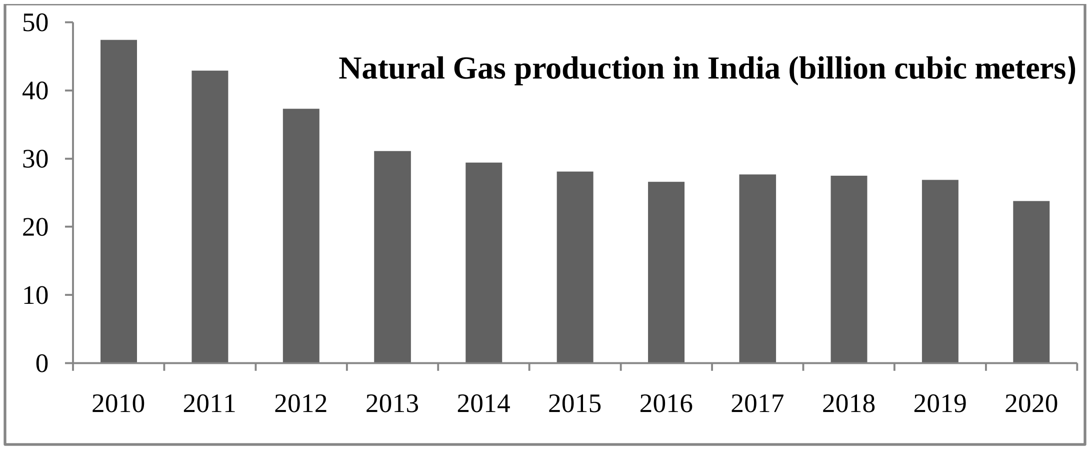


Figure 1.8: Natural Gas production in India (billion cubic meters)

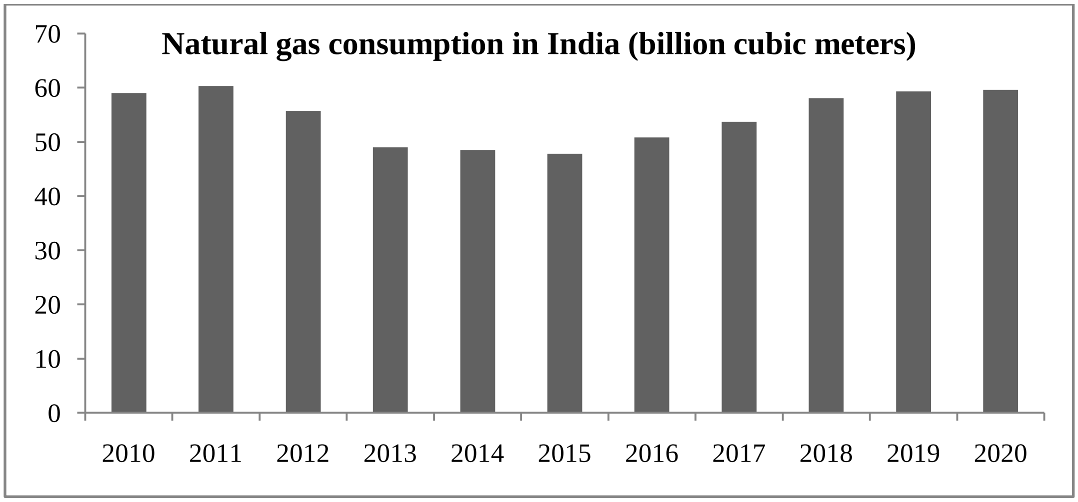


Figure 1.9: Natural gas consumption in India (billion cubic meters)

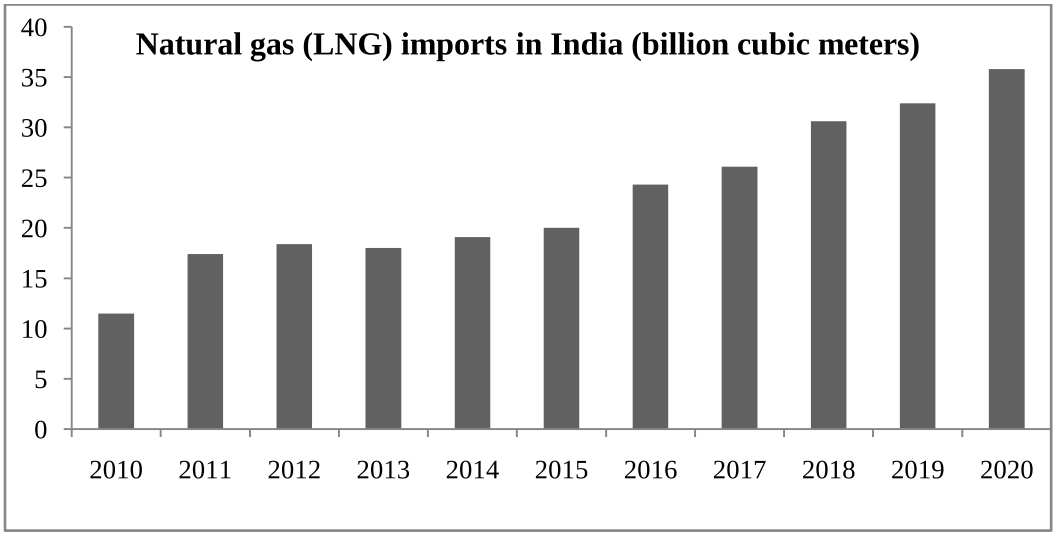


Figure 1.10: Natural gas (LNG) imports in India (billion cubic meters)

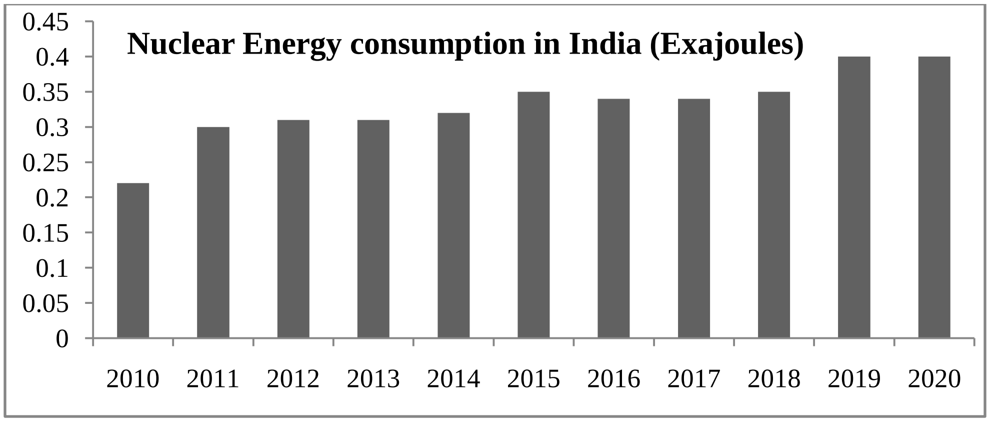


Figure 1.11. Nuclear Energy consumption in India (Exajoules)

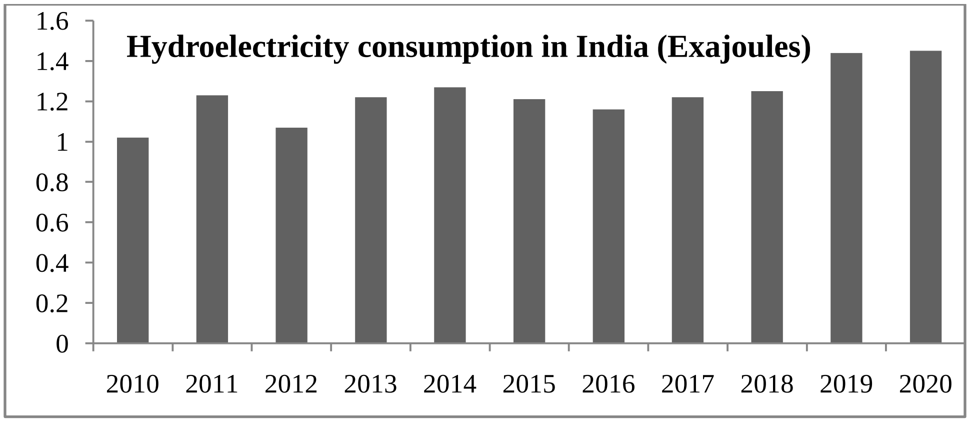


Figure 1.12: Hydroelectricity consumption in India (Exajoules)

1.2.5 Renewable Energy:

Renewable energy consumption has increased from 0.36 exajoules in 2010 to 1.33 exajoules in 2019, at a growth rate of 16.2% per annum (Statistical Review of World Energy 2021). In 2020, the consumption was recorded to be 1.43 exajoules which depicts a growth rate of 7.6% as compared to the previous year (Statistical Review of World Energy 2021). The consumption trend has been shown in Figure 1.13.

Renewable power generation in India saw an annual growth rate of 17.4% over the period 2010 to 2019(Statistical Review of World Energy 2021). In this duration, power generation increased from 33.9 Terawatt-hours to 139.2 Terawatt-hours (Statistical Review of World Energy 2021). In 2020, India achieved renewable power generation of 151.2 Terawatt-hours which is 8.3% more as compared to the previous year (Statistical Review of World Energy 2021). The generation trend has been shown in Figure 1.14.

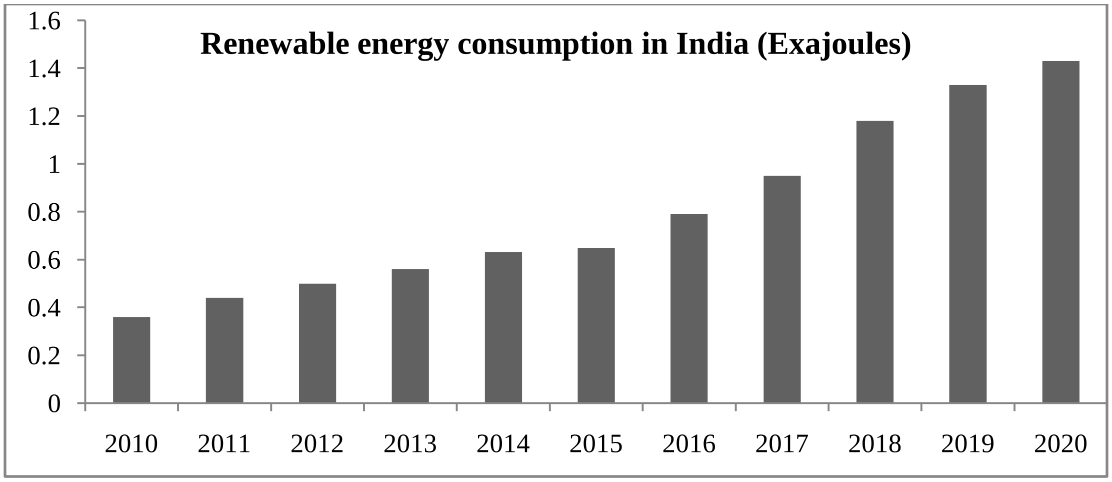


Figure 1.13: Renewable energy consumption in India (Exajoules)

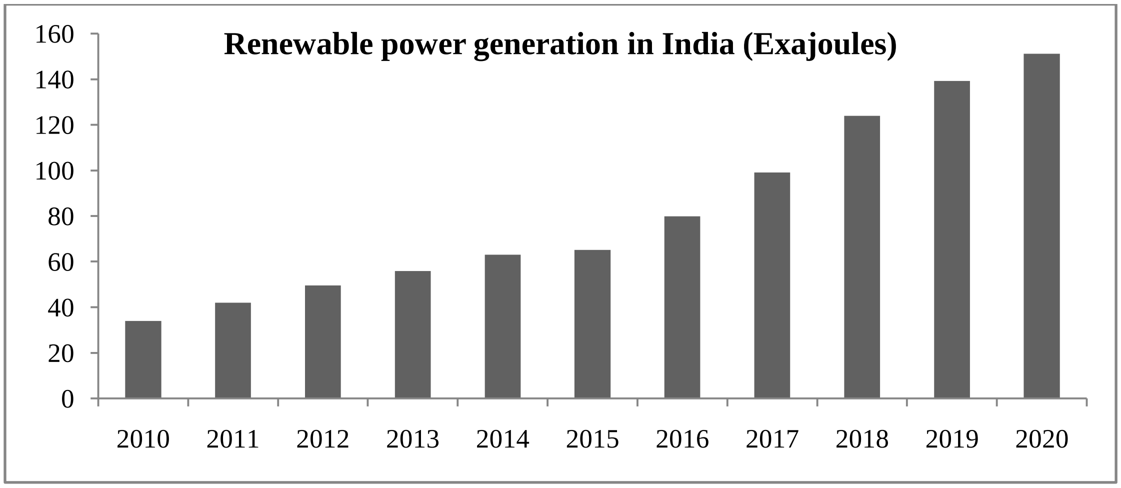


Figure 1.14: Renewable power generation in India (Exajoules)

Figure 1.15 shows the comparison of source-wise renewable energy generation in India in 2019 and 2020. Data showed that energy generation from wind declined by 4.8% in 2020 as compared to 2019 whereas solar energy generation grew by 26.5% in the same duration (Statistical Review of World Energy 2021). Also, renewable energy generation from other sources that included geothermal, biomass, etc. increased by 7.9% (Statistical Review of World Energy 2021).

Over the last decade, a lot of work has been done in order to increase the solar and wind capacity. India has increased its installed photovoltaic power from 0.1 gigawatts to 39 gigawatts and installed wind turbine capacity from 13.2 gigawatts to 38.6 gigawatts during the period 2010 to 2020 (Statistical Review of World Energy 2021). The same has been shown in Figure 1.16 and 1.17.

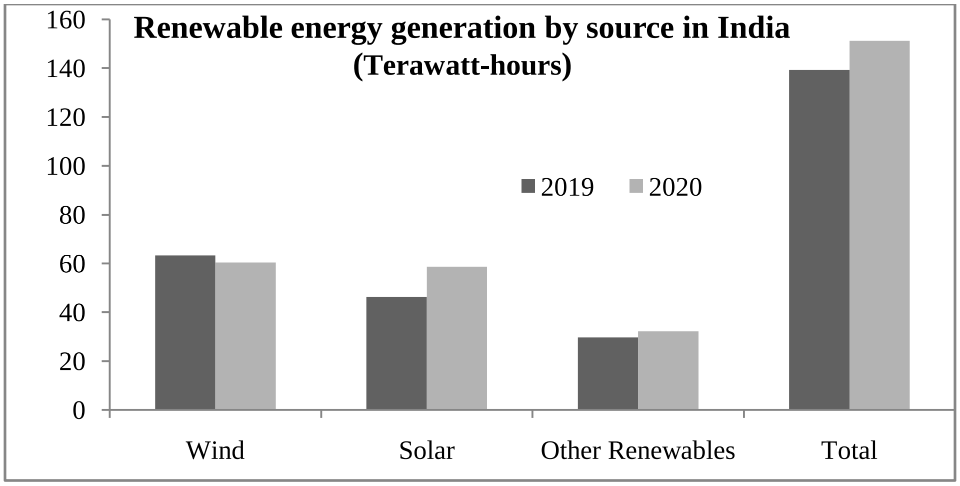


Figure 1.15: Renewable energy generation by source in India

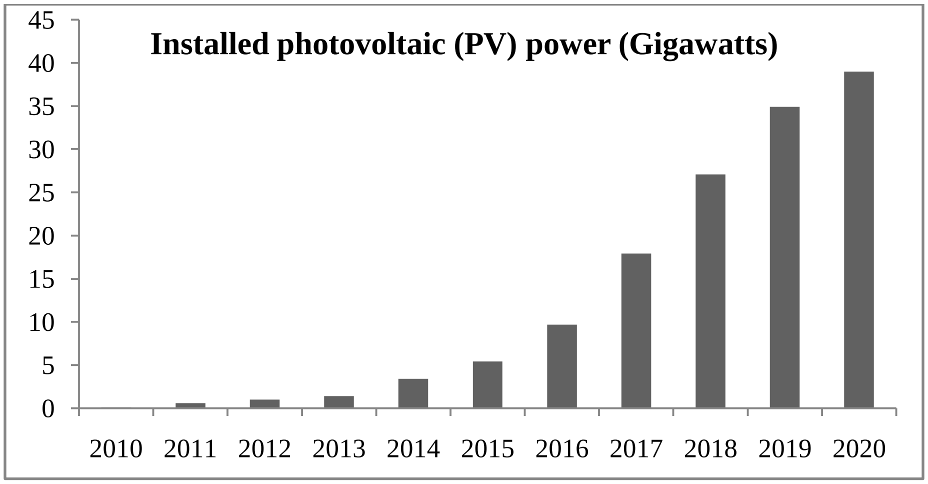


Figure 1.16: Installed photovoltaic (PV) power (Gigawatts)

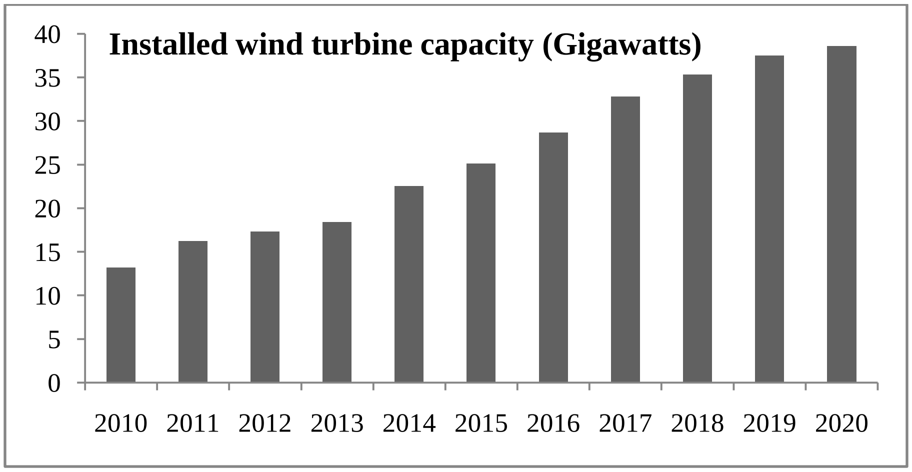


Figure 1.17: Installed wind turbine capacity (Gigawatts)

Work is also being done in the field of biofuels. India has increased its biofuel production from 3 thousand barrels of oil equivalent per day to 20 thousand barrels of oil equivalent per day (Statistical Review of World Energy 2021) during the period 2010 to 2020. At the same time, the consumption of the same has increased from 18 thousand barrels of oil equivalent per day to 39 thousand barrels of oil equivalent per day (Statistical Review of World Energy 2021). Figures 1.18 and 1.19 shows the trend in production and consumption of biofuels over the past decade respectively.

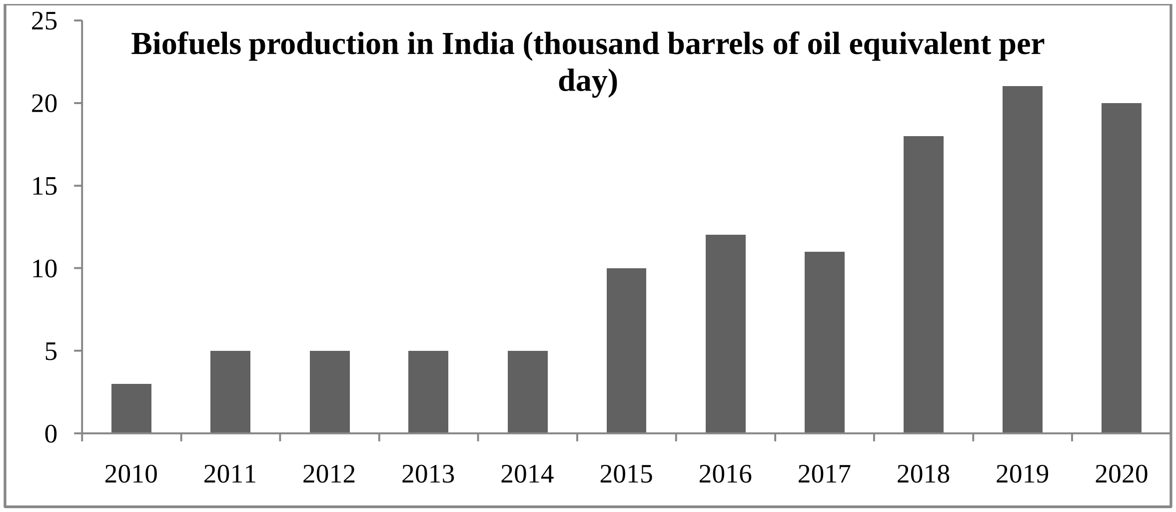


Figure 1.18: Biofuels production in India (thousand barrels of oil equivalent per day)

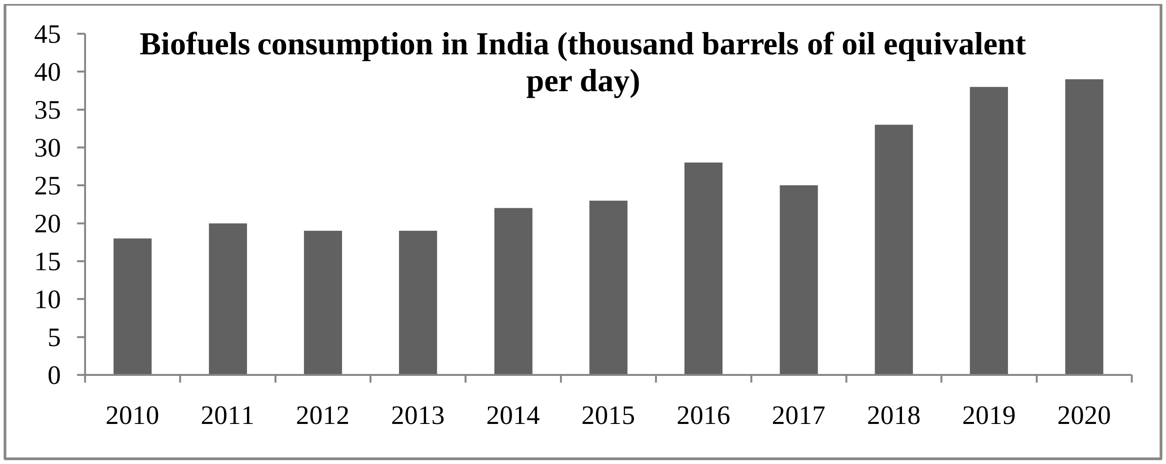


Figure 1.19: Biofuels consumption in India (thousand barrels of oil equivalent per day)

As already mentioned previously, coal oil and natural gas are the fuels that are majorly consumed in this country in various sectors.

Coal is mainly used in power generation and different types of industries such as cement industry, steel industry etc. Oil is widely used in various industrial sector, agricultural sector, transport sector, etc. Gas is used in industrial sector, transport sector, residential sector etc. Figures 1.20 – 1.24 shows the sector-wise consumption trend of above mentioned fuels over the past decade.

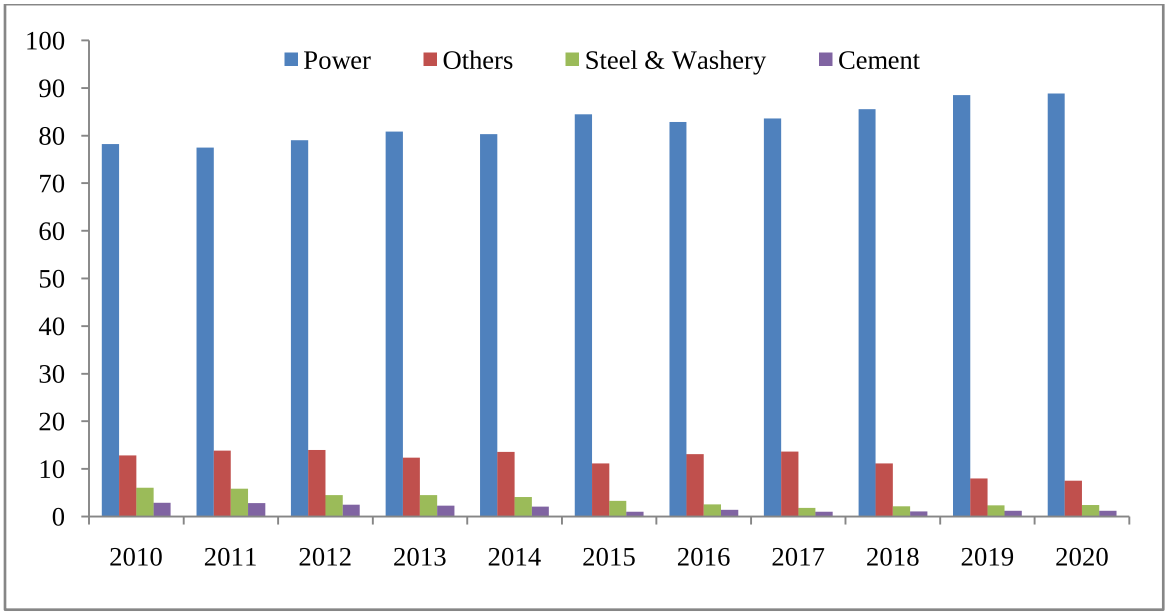


Figure 1.20: Sectorwise Domestic Coal Consumption (%)

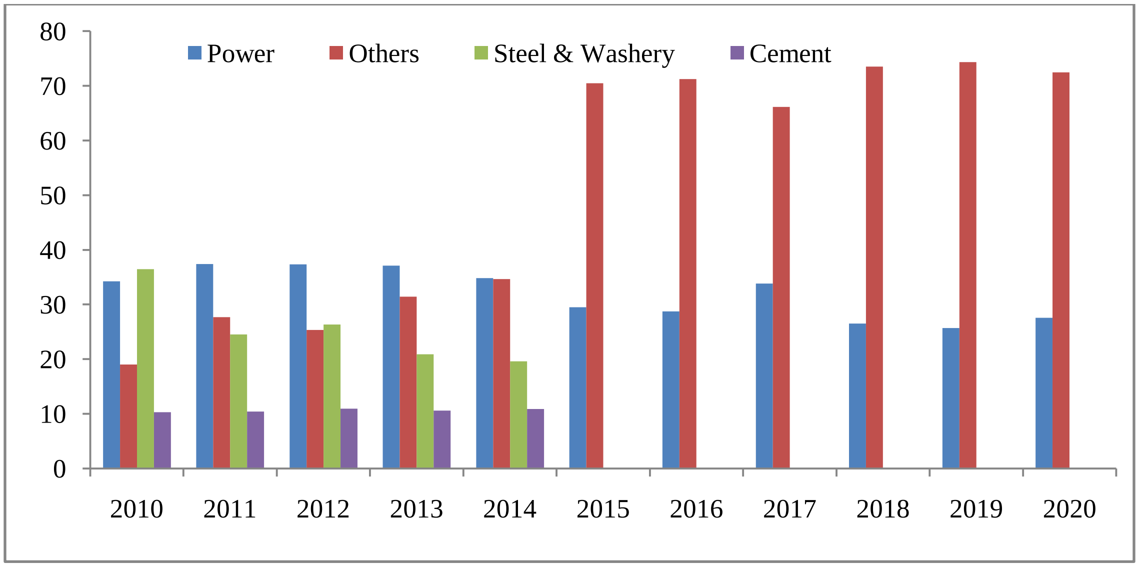


Figure 1.21: Coal imports in India (Exajoules)

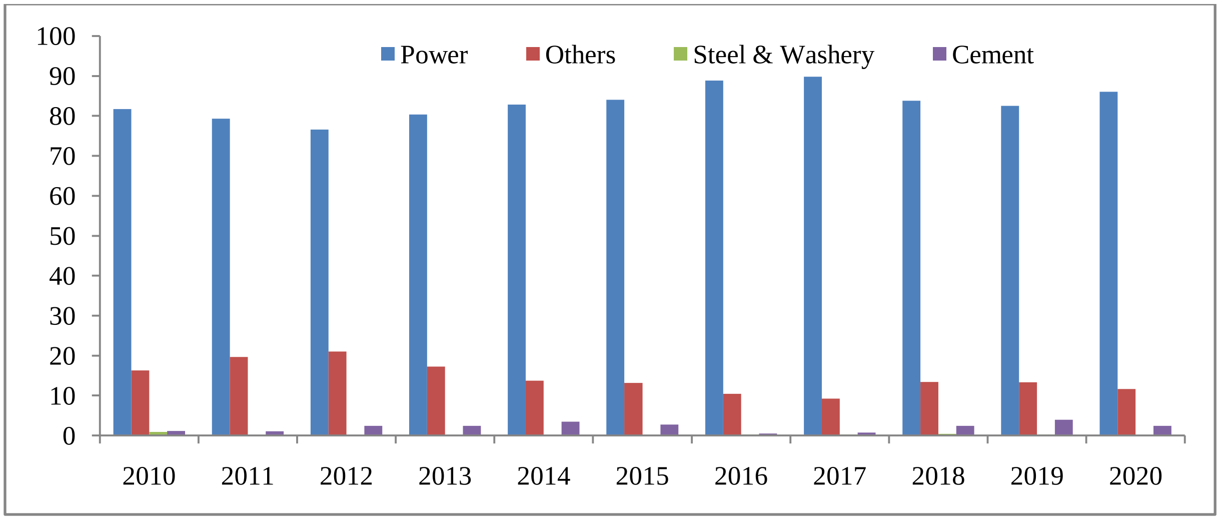


Figure 1.22: Sectorwise Lignite Consumption (%)

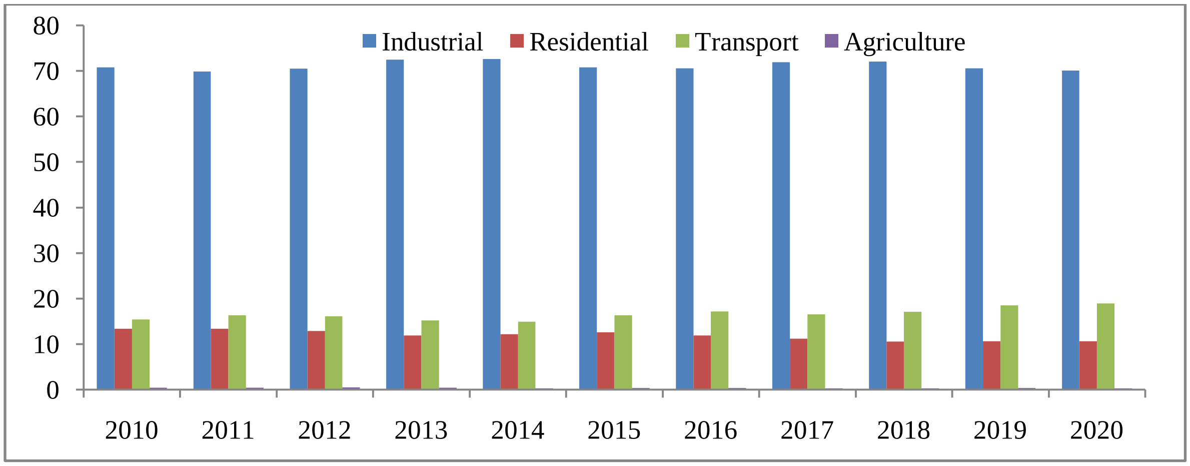


Figure 1.23: Sectorwise Oil Consumption (%)

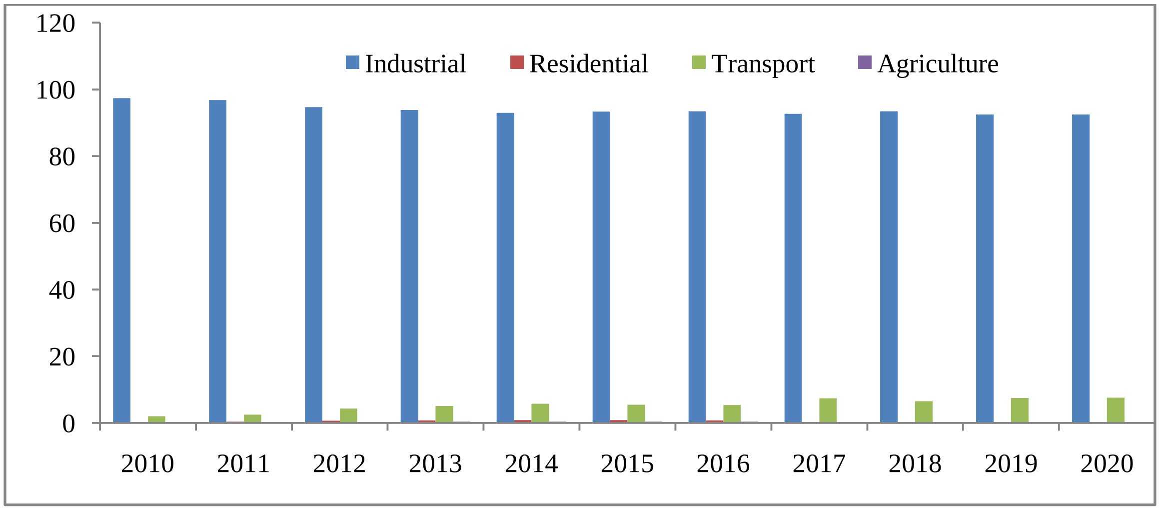


Figure 1.24: Sectorwise Gas Consumption (%)

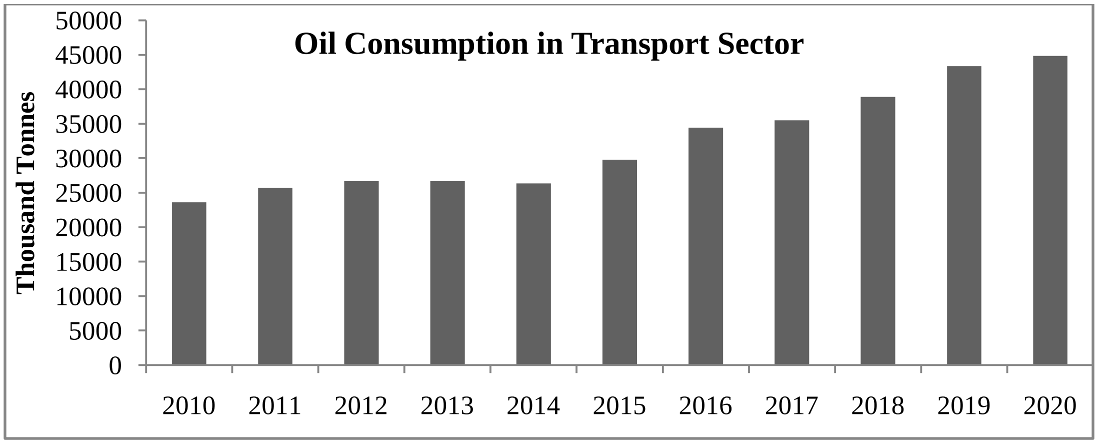


Figure 1.25: Oil Consumption in Transport Sector

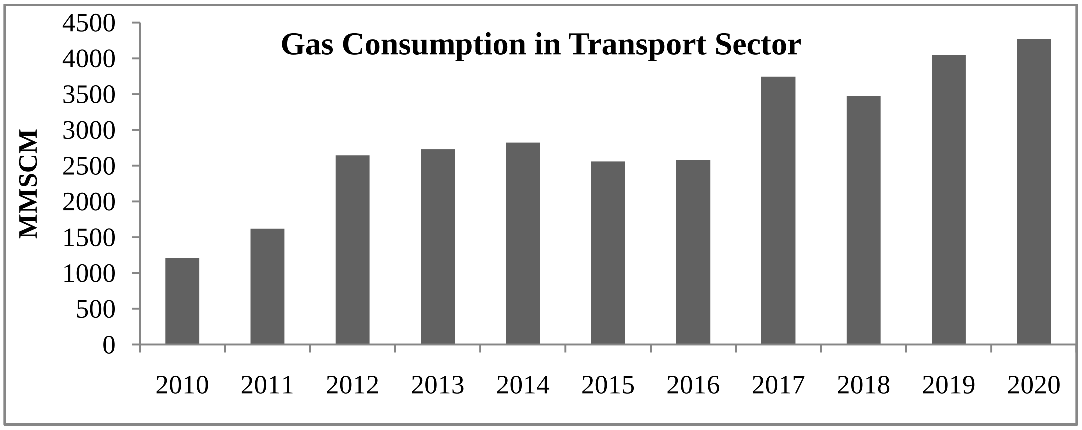


Figure 1.26: Gas Consumption in Transport Sector

It can be observed from Figures 1.25 and 1.26 that the overall consumption of oil and gas in the transport sector has increased gradually over the years. Clearly it is evident that transport sector has a considerable contribution in energy consumption. Figure 1.27 represents the schematic diagram of how the research area for this particular study was streamlined from overall study of energy. When classified broadly, energy is consumed in industrial, residential, agricultural and transport sectors. In 2020, Indian transport sector accounted for 50% of the nation’s total oil consumption (India Transport Energy Outlook, 2022). One of the reasons behind this is the increase in motorized passenger activity (1700 billion pkm in 2005 to 3833 billion pkm in 2020) (India Transport Energy Outlook, 2022). In addition, the freight movement in India has doubled (2250 billion tonne kilometers) in the same duration. Accordingly, petrol and diesel consumption has increased by 3 times and 2 times respectively between 2005-06 and 2019-20 (India’s Fuel Economy Benchmarks, 2021). If, somehow, energy consumption can be reduced, it will result in environmental as well as financial benefits to the country's economic by lowering the import burden.

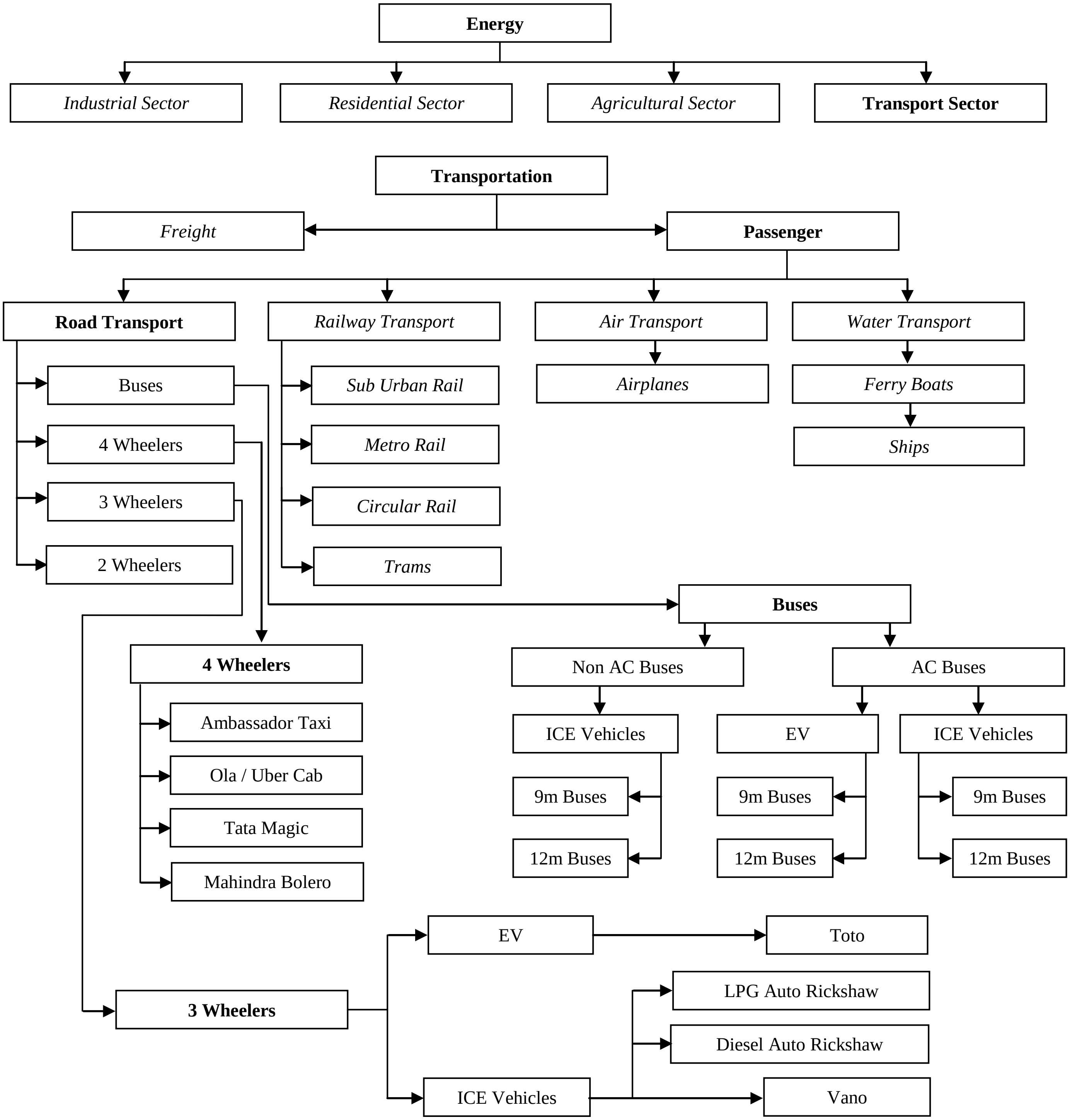


Figure 1.27: Schematic diagram of Transport Sector

1.3 Transport Sector in India:

The word ‘transportation’ means moving something from one place to another. It can be movement of goods or people. Based on these, transport sector can be classified into freight transport and passenger transport. Now, both freight and passengers can be transported by roads, railways, air and water. Out of 1325 billion tonnes km (TKM) of freight transport recorded in 2010, the share of air, water, rail and road was 1%, 6%, 36% and 57% respectively and projected share for the same in 2020 was 1%, 5%, 25% and 69% respectively (India Transport Report Moving India to 2032 Volume III).

1.3.1 Road Transport:

Road transport is the primary mode of transport in India. Extending over a length of 63.86 lakh km, the road network of India ranks second largest in world (Road Transport Year Book 2017-18 & 2018-19). According to National Transport Development Policy Committee 90% of total passenger traffic and 67% of freight traffic is carried by road transport (Road Transport Year Book 2017-18 & 2018-19). Total number of registered vehicles as on 31st March 2019 is over 295 million out of which 13.76 million vehicles are goods vehicle (India’s Fuel Economy Benchmarks, 2021).As on 31st March 2018, the total number of registered transport and non-transport vehicles was 23.96 million and 248.62 million respectively (Road Transport Year Book 2017-18 & 2018-19).

1.3.2 Railway Transport:

Railway network in India is the fourth largest in the world, after United States (224792 km), China (112000 km) and Russia (128000 km) (indianrailways.gov.in). As on 2019, its route length extends over 67956 km and it has 12729 locomotives out of which 39 are steam, 5898 are diesel and 6792 are electric (Indian Railways Year Book 2020 – 21). It runs nearly 21000 trains carrying more than 23 million passengers and 3 million tonnes of freight per day (indianrailways.gov.in).Indian Railways recorded 1050738 million passenger kilometers (PKM) and 707665 million net tonne kilometers (NTKM) in 2019 (Indian Railways Year Book 2020 – 21).

1.3.3 Air Transport:

Ministry of Civil Aviation, that governs and regulates air transportation in the country, reported 6.44 lakh scheduled flights carrying 71.6 million scheduled passengers in 2021 which represented a growth of 28.9% as compared to the previous year (civilaviation.gov.in). AAI Annual Report 2021 stated that during the period April to October 2021, total passengers handled by Indian airports were 833 lakhs (aai.aero). In 2019-20 the Indian airports handled 20.11 lakh MT of international cargo and 20.11 lakh MT of domestic cargo (aai.aero). Also, in 2018, India became the third largest market in terms of total passenger handled (aai.aero).

1.3.4 Water Transport:

Water transport is mainly used for freight transport. Passenger transport form a comparatively smaller part of water transport. Water transportation, regulated by Ministry of Ports, Shipping and Waterways, reported a fleet strength of 1491 vessels as on 31st December 2021 out of which 1027 vessels were engaged under coastal fleet and 464 vessels were deployed for overseas fleet (Indian Shipping Statistics 2021). Out of these vessels, 113 can carry passengers out of which only 68 are used for passenger service (Indian Shipping Statistics 2021). In India, there are 12 major ports owned by government and approximately 200 intermediate and minor ports (shipmin.gov.in). Indian ports handled 1251.38 million tonnes of cargo in the year 2021-22 (shipmin.gov.in). In 2020-21, the major ports handled 529.34 million tonnes of traffic till December, while the non-major ports handled 578.9 million tonnes (shipmin.gov.in).

The importance of mass transit has been established again and again in different studies. Public transportation helps to reduce road congestion, air pollution and energy consumption (fhwa.dot.gov). Abdallah (2017) studied the bus transportation in United State and emphasized that bus transportation could contribute to improving existing air quality and combat climate change.

Out of the various modes of transportation mentioned above, passenger transport by road has been selected in this case for further study. A closer look at passenger transport by road reveals that two types of vehicles are used for this purpose: commercial vehicles and private vehicles.

Commercial vehicles are for the use of masses whereas private vehicles are mainly for personal use. Different types of commercial vehicles that are used for mass transportation can be broadly classified under 6 wheelers (6W), 4 wheelers (4W), and 3 wheelers (3W). Also vehicles that have internal combustion engines and use fossil fuels to run are classified as internal combustion engine vehicles (ICEVs) and vehicles that use electricity to run are classified as electric vehicles (EVs).

Buses come under the 6W category. There are 2 types of buses, Air Conditioned (AC) and Non Air Conditioned (Non AC). These buses can also be classified based on their length. For this particular study, buses of 2 different lengths have been chosen; overall length over body excluding bumper 9000 mm with tolerance of ±400 mm (9m) and 12000 mm with tolerance of -100mm (12m) (Urban-Bus-Specifications-II). 4W category comprises of different types of cars. Taxis and cabs (Ola / Uber) are most popular in the metropolitan cities and urban areas. In the rural areas, these vehicles are replaced by vehicles like Tata Magic and Mahindra Bolero. Apart from these, there are 3Ws that take care of the last mile connectivity for daily commuters. Liquefied Petroleum Gas (LPG) auto rickshaws are most preferred within the cities. The streets of city outskirts and rural areas are ruled by Vano, Toto and diesel auto rickshaws. The vehicles mentioned above are mostly used by commuters when passenger transportation by commercial vehicles on road (in their respective locality) is considered. Hence these vehicles were chosen for this particular study.

Air pollution is a major concern and is responsible for 7 million deaths per year worldwide and is considered to be world’s largest environmental health threat (World Air Quality Report, 2021). In 2017, approximately 1.2 million premature deaths in India and about 4.7 million premature deaths worldwide were caused as a result of air pollution (Kuppili et al., 2021). In 2021, $PM_{2.5}$ was linked to the death of 40000 children under the age of 5 years (World Air Quality Report, 2021). Vehicular emission is a major contributor to air pollution. An estimated 20% to 35% of urban $PM_{2.5}$ concentration is attributed directly or indirectly to internal combustion engines in motor vehicles (World Air Quality Report, 2021). In order to curb the emission impacts, various emission norms were implemented. Over the years these norms were made more and more stringent as a result of which per vehicle emission was reduced to the tune of 85% (Kuppili et al., 2021). However this effect was nullified by increasing number of vehicles over the years. This is reflected from domestic vehicle sales data which grew at Compound Annual Growth Rate (CAGR) of 22% during 2001 and 2018 (Kuppili et al., 2021).Increased number of vehicles on road causes congestion which in turn can increase fuel consumption by 41% (Errampalli et al., 2016). Pollution levels for four cities, Delhi, Navi Mumbai, Chennai and Kolkata, as obtained from Central Pollution Control Board (CPCB), over the period of 2017-2020 has been shown in Figures 1.28-1.31.

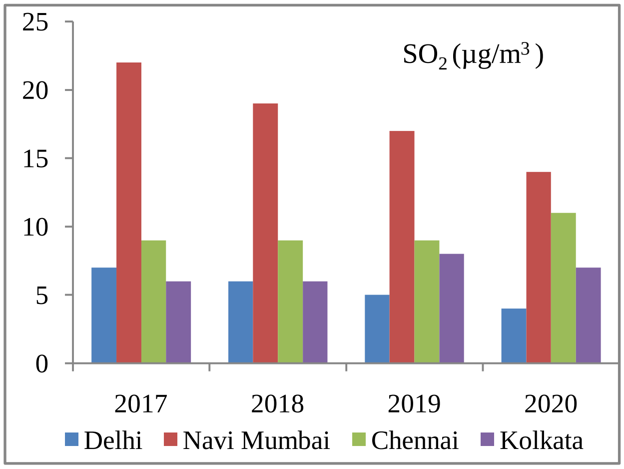


Figure 1.28: SO_2 Concentration

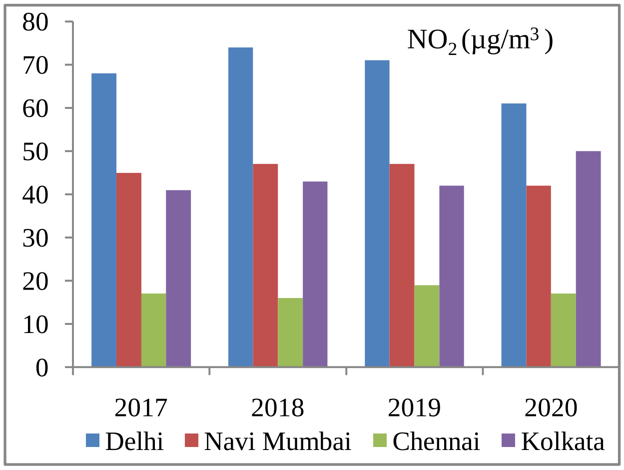


Figure 1.29: NO_2 Concentration

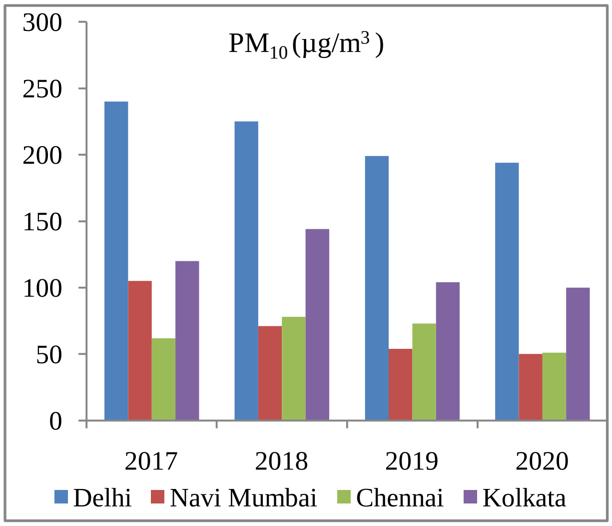


Figure 1.30: PM_{10} Concentration

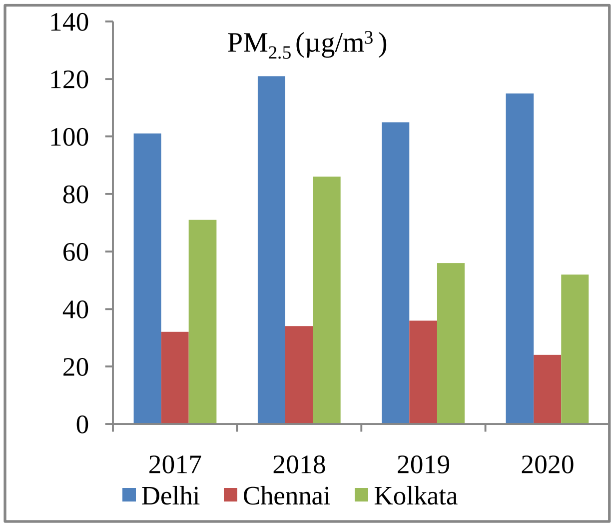


Figure 1.31: $PM_{2.5}$ Concentration

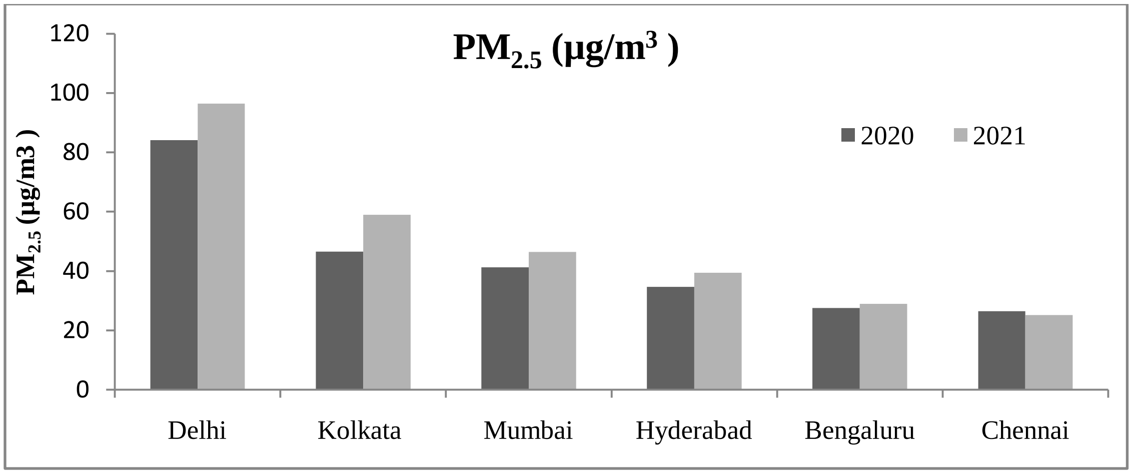


Figure 1.32: PM$_{2.5}$ Concentration for 6 major cities in 2020 – 2021(Source: World Air Quality Report 2021)

PM$_{2.5}$ concentrations for 6 major cities for 2020 and 2021 (**Figure 1.32)** shows increment in pollution levels for all the cities except Chennai. Conditions for Delhi and Kolkata are far worse as compared to the other cities. India's National Ambient Air Quality Standards (NAAQS) issued on November 2009 as well as Air Quality Guidelines (AGQs) issued by World health Organization (WHO) in 2005 and updated in 2021 has been shown in Table 1.1.

Table 1.1: Pollution level guidelines

Pollutants	**Average(µg/m^3)**	**NAAQS**	**WHO (2005)**	**WHO (2021)**
SO_2	Annual Average	50	-	-
	24 Hour Average	80	20	40
NO_2	Annual Average	40	40	10
	24 Hour Average	80	-	25
PM_{10}	Annual Average	60	20	15
	24 Hour Average	100	50	45
$PM_{2.5}$	Annual Average	40	10	5
	24 Hour Average	60	25	15

While considering NAAQS standards, although some cities show pollution level below permissible limits, when AQGs is considered, all the cities exceed the permissible limits by far. Also, reduction in the levels of permissible limit for pollutants in the air as per new WHO guidelines clearly depicts the severity of the situation. Consideration of all these facts forces the need for a deeper insight into the energy consumption pattern of vehicles. Only then, can proper mitigation techniques be designed and implemented.

1.4 Research Motivation

Indian road transport sector has been experiencing an increase in personalized mode of passenger transport, in the recent years, which has led to an increase in the traffic volume and decrease in passenger occupancy per vehicle (Tiwari and Gulati, 2013). Present trends and government policies have shown a transient phase in the road transport sector. Although the inclusion of electric vehicles has a promising approach towards energy efficiency, the changing traffic volume has led to the increase in congestion, thereby reshaping the on-road driving patterns and the traffic behavior. This in turn has increased the per capita energy consumption of the passenger transport sector. In this case, the personalized four wheelers (private cars) play a significant role. This very alteration in traffic behavior has led to a change in the on-road emission pattern for all conventional vehicles. Transport sector is a major consumer of energy in the form of fossil fuels and consequently one of the major contributors of air pollution in our country. In India, the total consumption of petrol in 2018–19, 2017–18 and 2016–17 was 28.3, 26.2 and 23.8 million tonnes respectively whereas the total consumption of diesel in the same year was 83.5, 81.1 and 76.0 million tonnes, respectively (thehindubusinessline.com). The total sales of passenger cars in India as on January 2019, 2018 and 2017 was 3,394,756, 3,229,109 and 2,966,637 units, respectively (ceicdata.com). Already thirteen Indian cities have made its place in the list of the top twenty most polluted cities in the world as reported in Global Ambient Air Quality Database 2018, published by World Health Organization (WHO). Along with the privatized mode of four wheelers, the road traffic share in the urban commute system is also critically utilized by the para-transit mode of transport that includes majorly the taxis and auto-rickshaws.

These vehicles are major energy consumers among all modes of passenger road transport system. There is no doubt that the situation is critical and demands immediate and utmost attention before it is too late. There are different approaches to address this particular issue. For example, use of alternative energy sources, use of improved vehicles having better emission standards, improved road infrastructure and traffic management, etc. Government of India has already initiated to phase out old commercial vehicles and mandated that only BS-VI compliant vehicles will be allowed to sell in India from 1 April 2020. Another way to address this issue is to minimize the energy consumption. Less energy consumption means less emissions and hence less air pollution. In order to minimize the energy consumption, it is important to identify the pattern of energy consumption and its variation with different factors.

Thus maintaining a sustainable transport system for all, and more importantly reaching the increasing transportation demand, India needs to realize alternative approaches for powering its transportation sector. This shift requires a strong analysis of the existing criterions on how the road vehicles are actually affecting the energy demand and what factors lead to the variation in demand, thus requiring an in depth study of the usage pattern depending upon the land use activities, based on regional divergence.

India cannot afford to increase the economic burden, thus a shift and variation in energy mix among fuels or other resources need to be identified based on characterization of vehicles where the shift/energy mix should be applied. The transition of energy resource/mix in the transport sector needs to be deployed in a progressive and phase-wise approach, requiring the analysis of the same in terms of consumption pattern, usage and behavioral impacts.

The shift towards EVs has found a great push owing to the globally improved technologies. However, EVs are also dependent on the energy mix strategy of the power sector, and consequently is their environmental performance. Moreover, electrification of vehicle fleet is a time strewed idea, thus the target towards net zero emissions demands exploitation of alternate fuel sources, like biofuels or methanol. Thus it is also dependent on the knowledge of energy consumption and vehicle usage characteristics based on which the energy shift strategy in the sector needs to be realized.

In this study a comprehensive outlook on the energy consumption pattern of the passenger transport sector has been undertaken. Moreover attempts in analyzing the transport sector in West Bengal based on regional variation have been quite rare. Based on the outcome of this study, technological progress and policy framing towards the transition pathway can be realized, portraying a vivid idea on the scopes of energy conservation aspects.

1.5 Aims and Objectives

Present energy consumption scenario along with pollution from vehicular emissions depicted the need for studying the energy consumption pattern in road transport sector. This thought process led to the survey of passenger vehicles in road transportation and it was assumed that survey results would reveal the energy consumption scenario. However, it was observed that the vehicles, driving patterns and traffic scenario varied over the regions. Hence a region based survey was conducted and regional energy consumption for different types of vehicles was analyzed. Although a consumption pattern emerged from the survey, it was unable to shed light on real world driving conditions and how it impacted the driving pattern of different vehicles. For this purpose an in-depth study was necessary. Literature revealed that studying driving cycles (DCs) were a popular method of interpreting fuel consumption from real world data. Hence an attempt was made at developing DC for different types of vehicles studied. From the 6W vehicle segment, DCs were developed for both ICE bus and eBus. DC was also developed for the 4W vehicle segment. DC for 3W segment has already been studied by Majumdar (2022) and was therefore kept outside the scope of this study. Study of DC was conducted in Kolkata. It was not possible to develop DC for all the regions studied because of time constraint, unavailability of resources and availability of limited funding. Further an attempt was made at estimating the per-capita emissions from the vehicles studied. Based on knowledge obtained thus far, attempts were made to identify the areas where energy could be conserved. Possibility of private bus operators adopting eBus in passenger transport was studied along with the impact of vehicle loading on energy consumption and vehicle mileage.

The objectives of this study may be summarized as:

- **To study the regional variations in energy consumption pattern for passenger vehicles in road transportation.**
- **To develop driving cycles for different types of vehicles that can reveal the difference in vehicle driving pattern based on real world data.**
- **To estimate fuel consumption of vehicles from driving cycle data.**
- **To estimate per-capita emissions from different types of vehicles.**
- **To analyze to possibility of private bus operators in Kolkata adopting eBuses.**

- **To study the impact of vehicle loading on energy consumption and vehicle mileage.**
- **To identify areas or ways in which energy may be conserved.**

Besides two-wheelers and three-wheelers, which are considered the most suitable candidates for electrification objective, buses are also considered to electrify the passenger-kilometers (pkm) as a basis of the Government initiatives as in FAME regulations. However, 4W segment in the EV sector has also seen a surge in numbers, but are minimal compared to the IC engine counterparts. It appears that a focused approach on estimating electric bus characteristics on road, based on vehicle trajectory data, is yet to be emphasized on. Since usage pattern throws light on the facts, whether the replacement of conventional buses have any marked impact on the traffic characteristics, it is a much required analysis relating to powertrain alteration objectives. Again, on similar grounds, real world usage pattern also throws light on the liked emission characteristics. Since electrification objective has been initiated already, it becomes imperative to compare their performance with respect to existing or conventional ICE counterparts. This will enable the pathway towards focusing on alternate fuels initiatives, considering net zero initiative as the prime objective towards sustainability (https://pib.gov.in).

Chapter 2 discusses the works of researchers that have been conducted in this field and tried to explore the research gap. Study of energy consumption pattern was conducted in two phase: a survey based approach and an experimental approach. The survey based approach has been discussed in Chapter 3. The experimental approach based on development of DC has been discussed in Chapter 4. This chapter also discusses the estimation of fuel consumption from DC data. Chapter 5 attempts at estimating the emission per passenger per kilometer from the different types of vehicles surveyed and identify ways of energy conservation. The possibility of private bus operators adopting eBuses has been discussed in this chapter. Also the impact of vehicle loading on energy consumption and vehicle mileage has been covered in this chapter. Final conclusions and scope of future work has been discussed in Chapter 6.

Abbreviations:

2W	Two Wheelers
3W	Three Wheelers
4W	Four Wheelers
6W	Six Wheelers
9m	Bus with overall length (over body excluding bumper) 9000 mm with tolerance of ±400 mm
12m	Bus with overall length (over body excluding bumper) 12000 mm with tolerance of -100mm
AC	Air Conditioned
AGQs	Air Quality Guidelines
CAGR	Compound Annual Growth Rate
CPCB	Central Pollution Control Board
EVs	Electric Vehicles
ICEVs	Internal Combustion Engine Vehicles
LNG	Liquefied Natural Gas
LPG	Liquefied Petroleum Gas
NAAQS	National Ambient Air Quality Standards
Non AC	Non Air Conditioned
NTKM	Net Tonne Kilometers
PKM	Passenger Kilometers

Chapter 2

Literature Review

2.1 Introduction:

Transport sector is crucial, considering its impact on regional as well as economic development. Moreover, its impact on energy consumption and atmospheric pollution due to vehicular emission cannot be ignored. All these factors have evoked interest among researchers all over the world and as a result profound number of studies has been conducted in this field over the years. Researchers have explored various areas related to transport sector such as energy consumption, pollution, government policies, driving cycle, electric vehicles, etc. These research works have contributed partly in understanding the sector and guided in shaping the present study. Some of these works have been discussed in the following section.

2.2 Literature Review:

Tanczos and Torok (2007) studied the connection between climate change and energy consumption from the road transport sector of Hungary and observed that transport sector was responsible for more than one-fourth of total CO_2 emission caused by human activities. The study revealed a strong correlation between atmospheric CO_2 concentration and average temperature of Earth. Assuming perfect burning of fuels like petrol and diesel, the total CO_2 emission in Hungary for 2003 was estimated to be 10.5 megatons. A strong correlation was also observed between economic activity and environmental pollution. The researchers observed that 1% change in motorization in European Union (EU) impacted carbon emission by 0.019%. It was suggested that if economic activity and transport activity could be decoupled, it would be beneficial from the perspective of environmental pollution and that one of the approach to achieve the same would be to switch to usage of alternative cleaner energy sources. Song et al. (2014) studied the implications of changes in transport sector on energy consumption and energy efficiency in Shanghai. It was observed that energy consumption increased at an average annual growth rate of 13.49% during 2000 to 2010. 94.49% of this energy demand was met by oil. Among the various modes of transportation available, water transportation accounted for more than 50% of energy consumed. Private cars consumed maximum energy whereas rail transport consumed the least. The fuel consumption for buses and taxis per 100 km travelled varied between 35 – 47 l and 9 – 11 l respectively. In order to improve the energy efficiency in urban transport sector, the researchers recommended integration of transport infrastructure, improving the efficiency of transportation capacity of public transport and mass production of new energy such as coal-bed methane, oil sand, geothermal energy, fuel ethanol and bio-diesel. Hao et al. (2015) developed future trajectories of energy consumption and Greenhouse Gas (GHG) emissions from freight transport sector in China. It was observed that energy consumption in freight transport sector increase at annual growth rate of 9.9% from 2000 to 2013. GHG emission from freight transport also increased in the same duration and accounted for 8% of nationwide GHG emissions in 2013. Rail, water and pipeline transport had least energy intensities as compared to other modes of transport such as road transport and aviation and that shifting from road to rail could reduce energy intensity by more than 90%. Different scenarios were considered for future projections: business as usual (BAU) and different levels of mitigation. Under BAU scenario, energy consumption would reach 453 million tonnes oil equivalent (mtoe) in 2050 at a growth rate of 7.9%, 3.6%, 1.6% and 0.1% for every 10 year period from 2010 to 2050. GHG emissions showed similar growth trend and would peak at around 2045 at a value 2.4 times the level observed during 2013. With 80% of total energy consumption, road transport would dominate energy scenario followed by water transport with 15% share. Under various mitigation scenarios, GHG emissions could be reduced from 16% to 32% by 2050. If maximum mitigation is considered, GHG emission would peak at around 2035 at 1375 mt CO_2e. In order to improve the situation, researchers suggested reconciling production and consumption locations to reduce freight transport demand, and tightening fuel consumption and emission regulations since vehicle emission standards in China is lagging EU standards by more than 5 years. Liu et al. (2015) constructed a Beijing urban passenger transport carbon model (BUPTCM) and simulated energy consumption and CO_2 emissions based on sensitivity analysis. Changes in share rate of transport mode for the same were observed considering various scenarios: BAU, priority to development of public transport (PDPT), travel demand management (TDM), technical progress (TP), administrative rules and regulation management (ARM) and comprehensive policy (CP). In BAU scenario, share rate of rail transit showed a growth from 12.3% to 19.5%, share rate of bus showed a decline from 26% to 20%, and share rate of cars showed a decline from 37% to 34.3% during 2011 to 2020. Share rate of taxis were expected to rise a little. In PDPT scenario, share rate of public transport was expected to increase by more than 60% in 2020, with sharp increment in share rate of rail transit, slight decline in share rate of bus and considerable decline in share rate of cars. TDM and TP scenarios reflected similar conditions to BAU scenario and depicted the share rate of cars to be around 35% in 2020. Arm scenario depicted sharp decline in share rate of cars and steady increment in share rate of rail transit. In CP scenario, share rate of cars is depicted to decline from 21.9% to 8.1% whereas share rate of public transport is depicted to increase from 45.3% to 85.1% during 2011 to 2020. As far as energy consumption is concerned, cars would contribute to more than 88% of energy consumption rising at an annual average growth rate of 4.44% from 2011 to 2020. In case of CO_2 emission similar trends were predicted during the same period. It was observed that both ARM and TDM policies were highly effective in improving consumption scenario but CP proved to be the best among all. Researchers suggested that optimal sequence in which the policies should be implemented was TP, PDPT, TDM and ARM. Chukwu et al. (2015) studied the energy consumption in transport sector of Nigeria and observed that this sector accounted for one third of country's energy demand and was the highest consumer of petroleum products for past 2 decades. Road transport was responsible for consuming 90% of total energy consumed by transport sector while marine transport and aviation industry accounted for less than 1% and 8% respectively. Passenger transport was responsible for 60% - 70% of energy consumption considering all transportation activities. Amongst the fuels, gasoline accounted for 58% and diesel accounted for 24% of the total petroleum product consumption. Transport sector was responsible for 70% of total fossil fuel consumption, out of which the share of urban passenger, inter-city passenger and freight was 47%, 30% and 18% respectively. 5% of consumption was attributed to miscellaneous causes. The share of cars, public buses and other vehicles including motor-bikes in passenger urban transportation was reported to be 76%, 18% and 6% respectively. In case of inter-city passenger transportation, the share for cars, buses, diesel rains and planes were reported to be 61%, 30%, 1% and 8% respectively. Researchers suggested utilization of cleaner fuels, infrastructural development, implementation of government policies, utilization of efficient vehicles and introduction of bus rapid transit (BRT) system to improve the situation. Azam et al. (2016) attempted to estimate energy consumption and emissions from road transport sector in Malaysia over the period of 2012 to 2040 using long-range energy alternatives planning (LEAP) model. Estimates were evaluated under BAU scenario, and alternative fuel policies of biodiesel vehicles (BIO), hybrid electric vehicles (HEV) and natural gas vehicles (NGV). In case of BIO scenario, it was assumed that all diesel vehicles would use a mixture of processed palm oil and diesel in the ratio 10% to 90% by 2025. For HEV scenario, it was assumed that by 2025, 5% of all on road vehicles except motorcycles would be HEV and by 2040 this share would increase to 10%.

In case of NGV scenario, it was assumed that by 2025, 15% of all petrol and diesel vehicles except motorcycles would be substituted by vehicles using natural gas and by 2040 this share would increase to 30%. Under such assumptions, it was observed that energy consumption grew at compounded annual growth rate (CAGR) of 4.8% in BAU scenario, 4.6% in BIO scenario, 4.7% in HEV scenario, and 3.8% in NGV scenario between 2012 and 2040. The share of petrol and diesel in total fuel consumption would be reduced to 95% and 99.8% respectively due to implementation of HEV and NGV policies in 2040 which would be otherwise 99.9% in BAU scenario. Share of electricity consumption would reach to 4.7% in HEV scenario in 2040 as compared to 0.02% in BAU scenario. Share of natural gas would reach to 0.04% in NGV scenario whereas share of biodiesel would reach to 2.3% in BIO scenario. NGV scenario projected highest reduction in energy consumption with a mitigation potential of 25.02% as compared to BAU scenario. With 5.03% reduction, BIO had the second highest mitigation potential whereas HEV scenario projected the least mitigation potential (3.91%) as compared to BAU. As far as emissions are considered, annual average increase in CO_2 emissions from 2012 to 2040 were projected to be 4.8%, 4.6%, 4.7% and 3.7% for BAU, BIO, HEV and NGV respectively. NGV scenario achieved highest mitigation as compared to BAU. CO emissions projected a CAGR of 5.2%, 5.18%, 4.9% and 4.1% in BAU, BIO, HEV and NGV scenarios respectively. CAGR for NO_X emissions were 4.7%, 4.67%, 4.4% and 3.6% for BAU, BIO, HEV and NGV scenario respectively. Non-methane volatile organic compounds (NMVOC) projected a CAGR of 5.2%, 5.17%, 4.9% and 4.1% for BAU, BIO, HEV and NGV scenarios respectively. For all the emissions, NGV scenario depicted maximum mitigation potential.

S.A. Neves et al. (2017) attempted at studying the dynamic linkage between economic growth, fuel consumption from various energy sources in transport sector and CO_2 emissions using Driscoll-Kraay fixed effect estimator followed by Autoregressive Distributed Lag (ARDL) structure. This study highlighted that although use of electricity in transport sector is contributing to reduce the usage of fossil fuels, historical data showed a negative impact on economic growth which could reflect high associated cost of transport sector electrification, and increment in CO_2 emissions from electrification which could be a consequence of burning fossil fuels to supply electricity. It was observed that although investments in railways, both new and existing trains, has contributed to a shift in using trains over private cars, thereby reducing use of fossil fuels, the increase in electricity demand for running the trains have contribute to larger CO_2 emissions. The study emphasized that although use of renewable contributed to reducing environmental impacts, its negative impact on economic growth should not be overlooked and that the policy makers should ensure the same by exploring the options of generating electricity using cost effective renewable sources such as wind and solar photo voltaic (SPV). Wang et al. (2017) analyzed energy consumption and CO_2 emission reduction in China's transport sector based on 5 scenarios using Transportation Mode-Technology-Energy-CO_2 (TMOTEC) model. The scenarios considered were reference (REF) scenario, energy efficiency improvement (EEI) scenario, promoting electric vehicle (PEV) scenario, additional tax increase (ATI) scenario and comprehensive (CPR) scenario. It was observed that passenger volume increased to 22.54 trillion passenger km (PKM) in 2050. Urban areas projected increment in passenger share in private cars (76.4%) and decrement in case of urban buses (18.1%) in 2050. Civil aviation and private cars showed an increment of 15% and 29% respectively for intercity areas in 2050. Domestic freight volume was projected to increase to 29.4 trillion tonne km (TKM) at an average annual growth rate (AAGR) of 2.8% and the share of road transport in freight volume was projected to increase to 51% in 2050. Numbers of cars were projected to increase to 532 million in EEI scenario whereas numbers of electric vehicles (EVs) were projected to increase to 77 million in PEV scenario. The population of EVs, trains and vehicles using biofuels were projected to increase in ATI scenario whereas number of EVs in CPR scenario was projected to increase to 94 million in 2050. In REF scenario, energy consumption was projected to increase at AAGR of 3% with gasoline, diesel, bioethanol, jet fuel and electricity accounting for 41.2%, 35%, 7.6%, 5.2% and 3.9% of total energy consumption in transport sector respectively. CO_2 emission in same scenario was expected to increase at AAGR of 2.8% with passenger transport, urban, intercity, rural and freight transport accounting for 63%, 37%, 21%, 5% and 37% respectively. EEI, PEV and ATI scenarios had the potential to reduce CO_2 emissions by 67 million tons, 159 million tons and 318 million tons respectively as compared to REF scenario in 2050. CO_2 reduction potential for CRP scenario was projected to be 494 million tons in 2050 as compared to REF scenario. Reddy and Balachandra (2012) compared the trends in mobility of people through motorized road transport in 23 cities and studied its implications on energy demand and carbon emissions. Fuel (petrol and diesel combined) consumption increased from 2.1 million tonnes in 1981 to 4.72 million tonnes in 2005. AAGR for petrol and diesel consumption was 17.1% and 5.4% respectively. Per capita consumption of transport energy for smaller cities like Coimbatore and

Ludhiana (around 3 GJ per capita per year) was observed to be higher as compared to mega cities like Mumbai (0.65 GJ) and Kolkata (0.7 GJ). Private transport mode was observed to carry 25% of estimated passenger traffic in PKM whereas 75% was carried by public transport. With 7200 PKM per capita, Delhi and Bangalore had higher mobility as compared to Kolkata and Mumbai (less than 2000 PKM per capita). Average annual automobile PKM per capita for larger and smaller cities was observed to be 4400 PKM and 6300 PKM respectively. Public-private transport ratio declined for most cities during 1991–2005 which indicated a shift towards private transport. Highest ratio was observed for Cochin (11.1) and lowest for Ludhiana (0.93). Energy intensity for cars (1.27 MJ/PKM) was observed to be higher as compared to a bus (0.2 – 0.3 MJ/PKM). In case of public transport for all the cities, energy use per PKM varied between 0.25 MJ/PKM and 0.52 MJ/PKM. Energy consumed for personal travel increased by 8% per annum during 1981 – 2005 and energy consumed per PKM for private transport, considering all cities together, was observed to be 2.5 times higher as compared to public transport. Average urban mobility intensities remained around 0.4 MJ/PKM whereas transport energy intensities increased from 0.55 GJ/capita/year to 1.93 GJ/capita/year during 1981 – 2005. In the same duration, CO_2 emissions from road transport were observed to increase from 4.57 million tonne to 15.29 million tonne at 4.2% per annum. During the study period, vehicle density increased, travel energy intensity decreased and transport energy intensity increased. Similarly carbon intensity for travel decreased from 1980 to 1990 and then stabilized whereas carbon intensity for transport which was constant till 1990 was observed to increase. Researchers suggested encouragement of non motorized and public transport, tax enhancement on personalized vehicles and usage of cleaner fuels for improving the situation. Pinna et al. (2014) gave an overview of Indian transportation system along with energy consumption and emissions corresponding to different transportation modes. Two wheelers (2Ws) and passenger cars accounted for 72% and 13.3% of motor vehicle population. Share of buses declined from 11.1% in 1951 to 1.3% in 2009. Transport sector accounted for 6.6% of India’s gross domestic product (GDP) in 2008 – 09, out of which road transport contributed 4.8%. Air passenger traffic increased from 109 million in 2008 – 09 to 143 million in 2010 – 11. Travelling by bus accounted for 56% of total PKM travelled, which has increased from 1327 billion PKM to 2933 billion PKM during 1990 and 2004 at AAGR of 5.9%. Transportation by road, air and rail grew at AAGR of 6.4%, 6.2% and d3.6% respectively. Share of transportation by bus decreased from 61% to 55% whereas for cars, 2Ws and auto rickshaws, the share increased from 2%, 9% and 3% to 6%, 15% and 5% respectively. TKM transport increased by 3.1% annually during 1990 – 2004 with rail transport representing 58%, medium and heavy trucks representing 37% and light commercial vehicles representing 4% of total TKM in 2004. Usage of energy in Indian transport sector was projected to grow at 5.5% as compared to world average of 1.4% per year. Diesel and motor gasoline represented 90% of final energy consumed in transport sector in 2004 with jet kerosene and electricity representing 8% and 2% respectively. In 2020, transport sector was projected to account for 21% of total final energy use, while the sector was projected to grow at annual rate of 6.8% from 2005 to 2020. Energy consumption for trucks and air transportation was expected to grow at AAGR of 8.8% and 7.9% respectively. CO_2 emissions were projected to increase more than 2.5 times in 2030 as compared to 2008. In 2008, the contribution of electricity and heat sector to CO_2 emission was observed to be 56% as compared to 9% by transport sector. A well-to-wheel (WTW) approach adopted to study the consumption and emissions loads of different transportation modes carrying freight between Delhi and Mumbai revealed airplanes (493140 MJ) consumed more primary energy as compared to trucks (28809 MJ) and trains (11401 MJ). CO_2 emissions for airplanes, trucks and trains were recorded to be 32.79 tons, 1.90 tons and 0.75 tons respectively. NO_X emissions were 93.10 kg (airplanes), 19.72 kg (trucks) and 10.42 kg (trains) whereas non methane hydrocarbon emissions were recorded to be 19.892 kg (airplanes), 1.429 kg (trucks) and 1.259 kg (trains). SO_2 emissions were recorded to be 48.204 kg (airplanes), 2.339 kg (trucks) and 0.926 kg (trains) whereas PM emissions were 3.767 kg (airplanes), 0.431 kg (trucks) and 0.325 kg (trains). 3 main issues were highlighted in the study; First, air transport had high pollution load despite not requiring linear infrastructure; Second, rail transport, despite requiring infrastructure, could be most convenient option is used properly; Third, government imposed policies based on tank-to-wheel (TTW) approach when it should be based on WTW approach. It was observed that WTW approach, although obtained from European experiences, could be used to analyze situations in Indian context. Özener et al. (2018) developed a fuel consumption model based on IPG TruckMaker, 3D road modeling and AVL Cruise co-simulation environment to access fuel consumption of public transportation buses and validated the same in Istanbul Metrobus System. Simulation results matched with measurement results with exception of some mismatch points in engine speed simulation which could be attributed to engine dynamic behavior uncertainty. Scatter plots of 26 station full cruise fuel consumption and simulated and measured (target) data regarding engine torque revealed that the proposed model could provide accurate and reliable results. Average speeds recorded from measured and simulated results varied within the range of 1% - 3% whereas fuel factors varied within the range of 3% - 7%. Total fuel consumption for load conditions and directions varied within the range of 2% - 5%. For further analysis, the trip was divided into 4 load dependent acceleration zones: high engine load (HEL) with acceleration (Zone 1), HEL with deceleration (Zone 2), low engine load (LEL) with acceleration (Zone 3) and LEL with deceleration (Zone 4). It was observed that 76.74 %, 66.74 %, and 72.55 % of total fuel was consumed in Zone 1, 14.36 %, 9.85 %, and 16.86 %, of total fuel was consumed in Zone 2, 2.89%, 4.38%, and 4.62 % of total fuel was consumed in Zone 3, 6.01 %, 19.04, and 5.97 % of total fuel was consumed in Zone 4 for no load, half load, and full load trips at AZ direction respectively. It was concluded that this model could be used to investigate the alternative energy efficiency scenarios for alternative driving characteristics for a public transportation system. Karpate et al. (2018) showed an approach to model the energy consumption for heavy duty vehicles have under the effect of different legislative driving cycles. It showed a performance of 2.65 km/l in case of fuel economy and also validated the same with real performances of similar vehicles in India. It was also observed that an efficiency improvement of 36% may be achieved in heavy vehicles sector by different improvisations like improving thermal efficiency, reducing overall vehicle weight, etc.

Ramachandra and Shwetmala (2009) prepared decentralized emission inventories for road transport sector in India and observed that Indian road transport contributed 243.82 Tg CO_2 (94.5%). In 2004, CO_2 contribution from road transport sector was 2.3 times more as compared to 2000. CO_2 contribution of Maharashtra was maximum, 28.85 Tg (11.8%) followed by Tamil Nadu 26.41 Tg (10.8%), Gujarat 23.31 Tg (9.6%), Uttar Pradesh 17.42 Tg (7.1%), Rajasthan 15.17 Tg (6.22%) and Karnataka 15.09 Tg (6.19%). Average state-wise emission of CO, CH_4, NOx, SO_2, HC and PM were observed to be 3.62, 63.25, 20.26, 20.67 and 4.37 Gg, respectively. Among different type of vehicles, CO_2, NO_X, SO_2, and PM contributions for trucks and lorries were 28.8% (70.29 Tg), 39% (0.86 Tg), 27.3% (0.19 Tg), and 25% (0.03 Tg) respectively, which constituted 25% of the total vehicular emission of India. Similarly contributions of 2Ws in CO, CH4, and HC emissions were 23.7% (0.72 Tg), 46.4% (0.06 Tg), and 64.2% (0.46 Tg) respectively. Buses emitted 30.7% NOx (0.68 Tg) and 20.5% PM (0.03 Tg). Buses and omnibuses emitted more CO_2 as compared to 2Ws and passenger light motor vehicles. Out of 258.10 Tg of CO_2 emitted by transport sector in 2003 – 04, aviation, railways and shipping contributed 7.60 Tg (2.9%), 5.22 Tg (2%) and 1.45 Tg (0.6%), respectively. Total CO_2 emissions per unit area for metropolitan cities were reported to be 0.25 Tg/km^2 of out of which contributions of Chennai, Bangalore, Kolkata, Delhi and Hyderabad were 0.034 Tg/km^2 (13.5%), 0.032 Tg/km^2 (12.4%), 0.022 Tg/km^2 (8.7%), 0.02 Tg/km^2 (8%) and 0.018 Tg/km^2 (7.1%) respectively. Total CO_2 emissions from railways, shipping and aviation was reported to have increased by 24.2% from 2003–2004 to 2005–2006. Kuppili et al. (2021) studied the real world exhaust emissions for 58 passenger cars (54 diesel fueled and 4 petrol fueled) on urban roads of Delhi. AVL DiTest-1000 portable emission measuring system (PEMS), having an accuracy of ±0.002% vol for CO and O_2, ±0.3% vol for CO_2, ±4 ppm for HC and ±5 ppm for NO, was used to measure real time exhaust emissions at sampling frequency of 1Hz. Data was collected during the months of March, April, June, July and December in 3 different time slots (8:00 – 10:00 AM, 12:00 – 2:00 PM, and 4:00 – 6:00 PM) covering 5 different routes. Average emission factors for CO, HC and NO were observed to be 3.8, 0.3 and 0.54 g/km respectively. The study revealed that all the cars exceeded BS-IV emission limits for above mentioned pollutants in real world driving conditions. It was also observed that emission rates increased with speed and acceleration. Speed emission rates increased rapidly up to 40 km/h and stabilized between the range of 40 km/h and 60 km/h. Similarly emission rates were found to be stable within the range of ±0.5 m/s^2 and increased beyond this range. The city registered per day emissions of CO, HC and NO to be 60.8, 4.8 and 9.72 tonnes respectively. This study demonstrated the importance of monitoring real time exhaust emissions. Ghose et al., (2004) highlighted the severity of the issues related to air pollution and the challenges of solving the problem in selected traffic intersections of Kolkata city. Shyambazar to Rathtala, a specific region of North Kolkata was selected for this specific study. It was observed that the concentration levels for suspended particulate matter (SPM), respirable particulate matter (RPM), Oxides of Nitrogen (NO_x), Sulphur dioxide (SO_2), Carbon Monoxide (CO), and Lead (Pb) varied between 739.3 microgram per cubic meter ($\mu g/m^3$) ± 20%, 286.5 $\mu g/m^3$ to 421.4 $\mu g/m^3$, 125.9 $\mu g/m^3$ to 233.7 $\mu g/m^3$, 52.2 $\mu g/m^3$ to 105.9 $\mu g/m^3$, 3616.4 $\mu g/m^3$ to 6786.2 $\mu g/m^3$, and 0.302 $\mu g/m^3$ to 0.708 $\mu g/m^3$ respectively. A vulnerability index (VI) developed in the study showed that all the locations where the study was conducted were under stress due to pollution. In order to reduce emissions, this study emphasized on using fuels like LPG and CNG and replacing older vehicles. The authors suggested that taxing cars entering the city limits, imposing steeper parking fees, imposing environmental tax on vehicles, improving public transit system and incentivizing the use of same could be effective in achieving the same. Uncontrolled growth of vehicle fleet followed by improvement in road infrastructure can have worst outcome as far as urban air quality is concerned. For this purpose proper vehicle control strategies need to be formulated and corresponding cost benefit analysis needs to be undertaken. Dutta et al., (2021) conducted a study on gaseous and particulate matter emissions from the road transport sector of 25 cities having million plus population. Firstly, road transport based emission load for Kolkata was estimated. Then a city-wise GHG emission inventory was prepared based on emissions from road transport and GHG emissions per unit area were computed and compared for the 25 cities. It was observed that the green house gas (GHG) emissions per unit area of Kolkata city in 2017 were highest among the 25 cities. The study showed that in case of Kolkata, cars were responsible for 35%, 55%, 75% and 27% of total Carbon dioxide (CO_2), CO, Methane (CH_4), and particulate matter (PM) emissions respectively. Omnibuses contributed to 41% of NO_X emissions, taxis contributed to 83% of SO_2 emissions and two wheelers (2Ws) contributed to 36% of hydrocarbon (HC) emissions. The reported yearly emission of CO_2, CO, NO_X, CH_4, SO_2, PM and HC in 2015 was 10603.14 gigagrams (Gg), 126.15 Gg, 52.55 Gg, 7.85 Gg, 46.23 Gg, 4.10 Gg and 19.6 Gg respectively. In 2017, amongst the 25 cities studied, Delhi reported maximum CO_2, CO and CH_4 emissions (48317 Gg, 630 Gg, 65 Gg) where Kolkata reported 12757 Gg, 151 and 10 Gg respectively. Highest NO_X and SO_2, emission was reported by Bengaluru (121 Gg, 108 Gg) where Kolkata reported 59 Gg and 52 Gg respectively. In the same duration, Kolkata reported 5 Gg of PM and 24 Gg of HC emissions. As far as GHG emissions per unit area is concerned, in 2017, Kolkata topped the list in CO_2 (62.23 Gg/km^2), NO_X (290 Mg/km^2) SO_2 (254 Mg/km^2) and PM (23 Mg/km^2) emissions. Delhi reported maximum CO (808 Mg/km^2) and HC (178 Mg/km^2) emission per unit area whereas Chennai reported maximum CH_4 (89 Mg/km^2) emission per unit area. The study also projected that during 2025, the city of Kolkata will be responsible for emission of 21668.24 Gg, 272.81 Gg, 98.21 Gg, 16.9 Gg, 93.39 Gg, 8.6 Gg, and 38.55 Gg of CO_2, CO, NO_X, CH_4, SO_2, PM and HC respectively from its projected 2.79 million vehicles.

Gota et al. (2014) investigated the potential of improving fuel efficiency and reducing CO_2 emissions from Indian bus fleets. Data for 500 buses over a period of one year was collected and analyzed. It was observed that older buses with lower emission standards experienced lower fuel efficiency as compared to newer buses and that the deterioration of buses due to extensive use over the years dominated impacts of fuel efficiency reductions that could be achieved from improvement in emission standards. Though the bus depots recorded and documented maintenance works, no emission reduction policies were in place. Also fuel economy targets and achievements were not well-publicized. Annual distance travelled by different buses varied within the range of 10000 to 230000 km/year. It was also observed that due to operational issues, less fuel efficient buses travelled in long routes whereas more fuel efficient buses travelled in shorter routes. Identifying and rerouting 20 buses had the potential to save more than $30000 USD in a year. Unnecessary fuel consumption of 1.2 liters per day per bus was reported due to idling. Increase in bus speed from 15 km/h to 20 km/h resulted in 25% improvement in fuel efficiency thereby having the potential to save 4000 liters of fuel per year per bus. Khanna et al. (2011) examined the impact of introducing alternative public transport system on energy use and environment considering three scenarios: BAU, increased bus transit share, and increased share of metro rail. It was observed that cars, 2Ws and buses consumed 45%, 30% and 25% of energy consumed in passenger transport. In BAU scenario, energy use and pollution increased in a non linear fashion, with energy use projected to grow four times in 2025 – 26 as compared to 2005 – 06. Gasoline was projected to be major source of energy as well as vehicular emission. CO emission was expected to increase by four to five times in the same duration. Under increased bus transit scenario, share of bus is expected to increase from 39% to 75% during 2005 – 06 to 2025 – 26. Energy use is expected to increase by 250% while CO emission from vehicles is expected to double as compared to base year. Despite such a huge jump in energy consumption, it would still be 31% less and emission of various pollutants would reduce by 35% to 55% as compared to BAU scenario. Increase in share of metro rail scenario indicated 150% increase in energy use and emissions. This would still be a reduction of 65% as compared to BAU scenario. It was concluded that increase in share of metro rail would prove to be most beneficial as compared to other scenarios as far as energy consumption and vehicular emission is concerned. Kumar et al. (2018) studied various green transportation projects (GTP) initiated under clean development mechanism (CDM) to reduce emissions from transport sector in India. Nine projects were aimed at reducing baseline emission of 760504.69 t CO_2 while causing project emission around 275799.20 t CO_2. However, reduction of only 501952.70 t CO_2 emissions was achieved. Average values of baseline emission, project emission, and emission reduction from 9 GTP's were estimated to be around 84500.52 t, 30644.36 t, and 55772.52 t of CO_2 respectively.

Majumder et al (2019) proposed a public transportation system based on eBuses that can be used in cities having weak electricity distribution network. A detailed simulation model was developed and initial sizing methodology for proposed system parameters was presented. Various simulation studies were conducted taking into account daily and seasonal variations in electricity demands and transportation needs. Proposed systems were seen to function properly without adding additional burden to existing electricity distribution network. Tentative cost for the same and its comparison with existing transit system was also presented in the study. Majumder et al. (2021) conducted an economic analysis of superconductor based eBus transit system for Indian cities considering both capital expenditure (CAPEX) and operational expenditure (OPEX). 3 energy scenarios were considered: 100% from grid, 50% from grid and 50% from solar, and 100% from solar. It was observed that CAPEX for diesel bus was lesser as compared to that of eBus system while OPEX for diesel was more as compared to eBus systems. OPEX for eBus transit system was found to be more profitable when energy sources were 100% solar and it was concluded that benefits of eBus system increased as the consumption of renewable energy increased. Shrimali (2021) studied the need of subsidies for EVs and observed that 2Ws, 3Ws 4W taxis and buses do not need subsidies considering their cost competitiveness with comparable vehicles from ICE segment. However personal cars and long-haul trucks needed to be subsidized to the tune of one third to one half of the upfront costs. Upfront subsidy was found to be the most cost effective subsidy option while financing subsidies were found to be least cost effective. Per kilometer subsidy was found to be 19% - 31% more costly as compared to upfront subsidy. Li et al. (2021) constructed a two-step methodology, including a novel stochastic RF model and a cooperative kNN RF model, to improve prediction accuracy and enhance the response speed for electric bus energy consumption (EBEC). Data from 163800 journeys for 20 bus lines over 5 consecutive months were collected in Shenzhen, China were used to analyze the model built in this study. The test results showed that the stochastic random forest (RF) model performed great in all selected accuracy indicators; 1.281% for mean absolute error (MAE), 11.805% for mean absolute percentage error (MAPE), and 1.614% for root mean square error (RMSE). The performance was observed to be better under the scenarios of long journey distances, off-peak hours, and weekends. Accuracy in MAE using stochastic RF model was raised by 9.470%-51.144% as compared to the existing models. Comparison between the stochastic RF model and k nearest neighbor (kNN) RF model revealed that the later could achieve time saving of 97.142% with 1.795% reduction in MAE accuracy. Researchers concluded that kNN searching model could be utilized to reduce computational cost by sacrificing a little accuracy and proposed EBEC prediction models had the ability to assist in dynamic scheduling and real-time operation management of large-scale eBus fleets. Gorosabel et al. (2022) presented a standardized framework for micro scale analysis of potential charging locations for eBuses. Obstacles in installing of charging station for eBuses were identified and it was concluded that, provided appropriate environment, placing charging stations within inner city and electrifying bus routes was possible. It was observed that connecting chargers to grid could account for more than 60% of total project cost. While greenfield projects should incorporate space required for charging infrastructure, incorporating the same in case of brownfield projects may prove to be challenging as existing infrastructure may not allow room for further modifications. These areas would require tailor-made innovative solutions from industries. Big transport hubs were found to be more efficient and cost effective as compared to end-stop charging. Researchers suggested that efficient electrification of public bus services would require a trade-off between number of chargers required, number of routes to be electrified and the foreseeable congestion level at each charger.

Tiwari et al. (2015) studied the travel behavior in Udaipur, Rajkot and Vishakhapatnam and analyzed the impacts of improving built environment and infrastructure on travel mode shares, fuel consumption, emission levels and traffic safety for the cities of Rajkot and Vishakhapatnam. Three scenarios were developed; improving only non motorized transport (NMT), improving only bus infrastructure, and improving both NMT and bus infrastructure. Results of analysis showed benefits of improving NMT facilities and it was concluded that improving NMT will result in CO_2 benefits along with improved safety. Improving only public transport would have marginal impact on overall CO_2 emission reduction. Maximum CO_2 emission reduction can be achieved by improving both NMT and public transport infrastructure. Bansal et al. (2018) conducted a survey across Delhi, Bengaluru and Kolkata and estimated annual vehicle kilometers travelled (VKT), vehicle ownership of 2Ws and 4Ws, and preference of vehicle body type and used these model parameters, GDP and cell phone ownership data to predict future vehicle adoption. Vehicle usage frequency was observed to be same for the locations studied although vehicle kilometers driven per year were slightly more in case of Delhi. VKT for 4Ws was observed to be 8817 km/year/household. Residents from Kolkata reported lesser VKT for household 4Ws as compared to Delhi. Majority of respondents reported households owning or leasing 4Ws. 62% of these vehicles were cars, 10% were trucks or SUVs and 29% were vans. Maruti Suzuki was the most popular brand followed by Hyundai. Number of vehicles per person for Delhi was reported to be 0.238 and was expected to grow by 27% during 2015 – 2020 and additional 137% by 2030 for all the surveyed regions. Respondents were seen to generate 16.9 round trips per week and 25.9% of the trips or out-of-home activities were related to work. Results from the study suggested rise in likelihood of 4W ownership with income, household size and residence in Delhi or Bengaluru.

Kamble et al., (2009) proposed a methodology to develop driving cycles (DCs) from the real world data collected from heterogeneous traffic. Chase car technique was used for data collection and microtrip method was used for DC development. In this particular research, the methodology used for developing the DC takes into account different parameters such as the percentage acceleration, percentage deceleration, percentage idle, percentage cruise, and the average velocity. Values recorded for the same were 14.18%, 11.48%, 18.09%, 56.25% and 19.55 km/h respectively. Total duration of the DC was 1533 seconds. When compared, it was observed that average speed for Pune DC was 16% less as compared to Indian DC whereas average acceleration was higher by almost 120%. Average deceleration was recorded to be 133% higher for Pune DC when time spent in acceleration mode was 64% lower as compared to Indian DC. Vehicles in Pune spent 59% of time travelling at speeds less than 10 km/h, 22% of time travelling within range of 10 – 20 km/h. Congested traffic scenario in the region was established by the fact that vehicles spent 80% of time at speeds below 20 km/h. From the study it was concluded that Pune driving condition was characterized by high fluctuations due to traffic heterogeneity and congestion which would lead to high emission and fuel consumption. Nesamani and Subramanian (2011) developed DC for intra city buses in Chennai using 14 driving parameters and observed that a huge amount of time is spent in idling mode irrespective of the type of road or the duration of travel. This was mainly attributed to alighting and boarding of passengers at regular intervals delays due to stoppage of vehicles at traffic lights. Driving characteristics were observed to be more or less similar during peak and off-peak hours. Average speed for more than 90% of intra city bus trips were below 30 km/h which indicated frequent stop- and- go conditions. Researchers stressed the importance of city based DC for India and suggested proper training of drivers, implementing strategies like dedicated bus lanes and bus priority signals to improve traffic flow and fuel economy thereby reducing emissions. Bishop et al. (2012) proposed a robust data driven Markov Chain method for capturing real world behavior in DC without deconstructing raw velocity-time sequence of the test vehicle. The best candidate DC met all the nine metrics within 5% of corpus behavior for 135 velocity modes and cycle length of 500 seconds. It was observed that the accuracy of best candidate DC depended most on increasing the number of Markov repetitions. The accuracy was observed to increase with increasing number of velocity modes, but decreased with increase in DC length. Maurya and Bokare (2012) developed bus DC on state highway in Maharashtra by recording the speed-time data for 114 buses using GPS device at sampling rate of 1 Hz. Results showed that average speed for buses varied within the range of 31.10 km/h during evening peak hours and 44.60 km/h during off-peak hours. Difference between average trip speed and average trip running speed was highest during evening peak hours (9.3%) as compared to morning peak (5%) and off –peak hours (4.7%). Idling time was highest during evening peak hours (9.41%) as compared to morning peak (5.36%) and off-peak hours (4.22%). Drivers were more aggressive in morning and off-peak hours as compared to evening peak hours. Higher values of PKE during off-peak hours indicated that drivers used more energy and consumed more fuel during the off-peak hours as compared to morning and evening peak hours. Micro trips registered average speed of 41.86 km/h and maximum speed of 65.77 km/h whereas acceleration rates for the same varied between the range of -0.726 m/s^2 and 0.957 m/s^2. Fotouhi and Montazeri (2013) used the microtrip method to develop passenger car DC for Tehran. Advanced Vehicle Location (AVL) device was used to gather real time data from the various traffic scenarios in Tehran. The microtrips generated from the synthesized data was segregated based on *k-means* clustering approach, so as to find the stochastic relation between the percentage idling time of vehicle movement and average velocity. The final DC for Tehran had duration of 1533 s spanning a distance of 14.41 km, and an average speed of 33.83 km/h. This DC exhibited higher average speed, lower idling time, whereas fuel consumption and emission was reported to be in middle range. Adak et al. (2016) constructed the real world DC for three types of vehicles, motorcycles, auto rickshaws and passenger cars, based out of the city of Dhanbad. Shared auto rickshaws and motorcycles exhibited different driving characteristics and hence using same DC to estimate vehicular emissions would result in deviation from actual values. Emission simulation based on real world DC data revealed that emission factors for auto rickshaws were highest amongst the studied vehicles. Also DC for passenger cars showed huge variation with respect to time spent in different driving modes as compared to MIDC, thereby resulting in faulty emission estimates. Following real world DC, motorcycle took 1683 seconds to travel the study route and idling time was 49 seconds. In case of auto rickshaws, the same time durations were observed to be 3493 seconds and 325 seconds respectively. For passenger cars, it was 2697 seconds and 20 seconds respectively. Emission factors for auto rickshaws were found to be maximum as compared to the other vehicles studied. Badusha and Ghosh (2018) developed Delhi bus driving cycle (DBDC) considering 12 parameters. Data was recorded over 52.80 hours covering a distance of 897.123 km. Distance travelled by the vehicle on DBDC was 837 m for a cycle time of 170 seconds. In DBDC, vehicles operated more in the speed range of 0 – 30 km/h and percentage time spent in idling was more as compared to IDC. Maximum speed observed in DBDC was higher as compared to IDC.

Errampalli M. et.al. (2015) highlighted the effects of congestion on fuel cost and travel time cost on multi-lane highways of India. In this study, congestion cost relationships were developed between Congestion Factor and Volume-Capacity Ratio. Different types of vehicles such as two wheelers, small cars, big cars, heavy commercial vehicles, light commercial vehicles, and multi-axle heavy commercial vehicles were studied. Time related data was collected through questionnaire survey method and fuel consumption data was collected through V-Box fuel flow meter. A network survey vehicle was used to collect road geometry data. The study showed that congestion caused 41% extra fuel consumption and 48% extra time spent during the travel. The congestion effect on combined fuel and time cost was about 45% for cars and 2Ws and about 35% for buses. The optimum speed for petrol driven small cars, diesel driven big cars, 2Ws and two axle trucks were found to be 58 kilometer per hour (km/h), 62 km/h, 60 km/h, and 74 km/h respectively. It was also noted that the fuel consumption under steady state and congested conditions would be same for speeds exceeding 55 km/h, 60 km/h, and 45 km/h for small cars, big cars and two axel trucks, and 2Ws respectively. Sharma et al. (2019) observed that the fuel consumption and corresponding emissions at traffic signals was an effect of increased number of vehicles on road. The study was conducted at eleven representative signalized intersections of varying traffic volume in Delhi and it was observed that idling fuel losses at selected signals went up to an estimated value of 5747 l of petrol, 3063 l of diesel, 5461 kg of CNG and 226 l of LPG per day. Among the various categories of vehicles, cars constituted ~37% of the idling traffic and contributed maximum toward idling fuel losses. Estimates of idling fuel losses and corresponding emissions obtained from these eleven signalized traffic intersections were expanded to total 950 signalized traffic intersections in order to obtain a realistic estimate of total fuel losses and emissions for the city. Idling fuel losses at these 950 signalized traffic intersections were estimated to be 262,703 kl petrol, ~145,284 kl diesel, 248 kt CNG and 10,202 kl LPG per year. It was observed that nearly 60% of total idling traffic was formed by private vehicles, including cars and 2Ws while only 10% by public transport (3Ws and buses). Fuel losses in monetary terms were estimated to be 5.9 billion USD per year.

Choma et al. (2020) assessed the health impacts of electric vehicles through air pollution in the United States and inferred that substituting conventional ICE vehicles with electric vehicles in urban areas is clearly a better choice. Air pollution benefits alone resulted in mean benefit of $ 86000 per 160000 miles. This benefit amounted to $ 6900 when discounted over a period of 15 years (vehicle lifetime) at a discount of 3% per year. It was also observed that the most populous areas derived more public health benefits. Nimesh et al. (2020) conducted a viability assessment which showed that shifting from conventional vehicle to electric vehicle will decrease the CO and CO_2 emissions by 60% and 17% per unit vehicle respectively. However the SO_2 and NO_x emission per electric vehicle per 100 kilometer will be 89.22 grams and 24.82 grams respectively. The study also showed that the current degree of viability of electric vehicles in India is 0.9 and if the value can be brought down to 0.63 by increasing the share of renewable sources to 60% of total power generation, the emission of CO and CO_2 may be reduced by 72% and 42% respectively. Sharma and Chandel (2020) projected that in 2050, under current scenario of electricity generation, CO_2 emissions from all EVs except buses will be at least 40% less as compared to ICEVs. However the $PM_{2.5}$ emissions could be 126% and 326% more electric cars and buses. The study also mentioned that if the contribution of renewable energy sources can be increased in power generation, the CO_2 and $PM_{2.5}$ emissions from EVs would be decreased by at least 32% and 25% respectively.

Sheth and Sarkar (2021) attempted to compute social benefit cost analysis (SBCA) for the proposed electric bus rapid transit system (e-BRTS) in Ahmedabad. Various components of benefits and costs to road users and agency were identified and quantified. The present worth of these components was calculated, which revealed a benefit cost ratio greater than unity for the case. Researchers concluded that e-BRTS had substantial societal benefits and may be viewed as a fruitful investment for the city. Kumar and Chakrabarty (2020) compared the total cost of ownership (TCO) of electric variants of 2Ws, 3Ws cars and buses with their ICE counterparts. It was observed that TCO per km for electric two wheelers (e2Ws) and electric three wheelers (e3Ws) was less as compared to their ICE counterparts for typical average daily usage of vehicles in Indian cities. Hatchback and Sedan cars showed a different trend. TCO per km for electric cars (eCars) was observed to be higher than their ICE counterparts. In case of electric buses (eBuses), TCO per km for eBus was observed to higher than CNG buses due to high initial purchase cost. Increasing vehicle utilization has the potential to reduce TCO per km for both eBuses and eCars. Reduction in initial purchase cost can contribute to the same cause.

Carlson et al. (2013) measured impact of vehicle mass on road load forces and energy consumption for battery electric vehicle (BEV), hybrid electric vehicle (HEV) and ICE vehicle. It was observed that increasing vehicle mass impacted road load less than same amount of decreasing vehicle mass. It was observed that in city type and aggressive type driving, 10% mass reduction resulted in 3% - 4% reduction in energy consumption for the three vehicles studied. In highway type driving, change in vehicles mass did not appear to have large impact on energy consumption. Largest fuel savings as a result of mass reduction was observed for ICE vehicles. Ang and Deng (1990) studied the effects of maintenance on fuel efficiency of public buses. Based on expected level of impact on fuel consumption, maintenance was classified into three types: major, minor and ineffective. Results showed improved fuel efficiency after every major maintenance activity. Post major maintenance activity, the relationship between fuel efficiency and vehicle mileage was observed to be non linear. Also fuel efficiency dropped by 2.8% and 3.4% as vehicle mileage reached 3500 km and 7000 km respectively. Kobayashi et al. (2009) suggested that the performance of vehicles according to operating efficiencies may be considerably enhanced from 5 to 20% by observing the strategies of eco-driving, efficient tire replacement, better traffic management, improved maintenance, in-vehicle technological improvements, reduced idling and increased load factors. Load reduction was found to be important for vehicles using conventional fuels but crucial for those using energy sources with low energy density (hydrogen and electricity). The combined effect of load reduction and drivetrain improvements (without hybridization) for spark-ignited engine drivetrains could allow a 50% or greater improvement in new vehicle fuel economy while added use of full hybrid drivetrains could more than double fuel economy and more than halve GHG emissions. Anderson et al. (2016) studied the relationship between road characteristics and speed and observed that presence of road markings in both center and along the shoulders made drivers go faster (by 9 km/h) as compared to unmarked roads or roads having only center markings. Also, speed of the vehicles increased with width of road. Vehicle speed increased by 2.7 km/h for each km extra road ahead. Speed of vehicles reduced by 1.3 km/h per meter of increase in shoulder width and 0.3 km/h for each 10 cm increment in strip width. Vehicle speed increased by 0.2 km/h as the number of intersections per km of road increased by one. Average driving speed for male drivers were 1 km/h faster as compared to female drivers. Trips between 3:00 p.m. and 5:00 p.m. were 0.8 km/h slower as compared to rest of the day. Chen et al. (2016) studied the influence of width of urban branch roads on meeting of two-way vehicle flows and observed that depending on average vehicle velocity, branch roads required different widths to prevent large decrease in velocity when vehicles met. It was observed that when velocity on branch road was less (in the range of 6 m/s), increasing road width increased meeting velocity. However, when velocity on branch road was high (greater than 10 m/s), meeting velocity would decrease largely even if width of the road was high (approximately 6.5 m). Salgueiredo et al. (2017) performed a simulated and experimental evaluation of the concept of human runners inspired speed variation cycles with respect to fuel economy of conventional passenger cars. The experiment was performed with Renault Clio 3 Eco2/2008 model in a controlled flat test track condition. The study revealed that speed variations correlate to lower fuel consumption while decelerating with gear in neutral position, both in experiment and in simulation. The study proved that the Pulse and Glide strategy is efficient in terms of fuel economy. Fontaras et al. (2017) reviewed the influence of different factors affecting the fuel consumption and CO_2 emission of European passenger car fleet. Influential factors such as driving behavior, vehicle configuration, traffic conditions and neglected factors such as side winds, rain and road angle, etc. were discussed. The study revealed that though the margin of present certification process contributed 10–20% in the gap between the reported value and reality, actually it was estimated to be of the order of

40%. Based on the traffic conditions, the same could vary in between 19 and 60%. Although it is very difficult to properly replicate the real-time driving conditions in any test facility, the study emphasized on introduction of new test protocol that can reduce the present divergence between the laboratory and real world. Miotti et al. (2021) observed that modifying driving styles can contribute to reduce energy consumption and emission without requiring any change in infrastructure or vehicle technology. These modifications in driving style did not require any real time feedback or onboard diagnostics. The simulated driving style improvements resulted in average fuel savings of 6% per trip. However the trip duration was observed to increase by 1.5%. Early decelerations and reduction in highway speeds had the potential of increasing fuel savings substantially whereas gradual accelerations had lesser contributions on the same.

2.3 Conclusion:

Reviewed literature revealed energy consumption scenario related to road transport sector for different regions and forecasted that the consumption would increase over time along with pollution from vehicular emissions. Vehicle population has increased all over the world and a shift has been observed towards personalized mode of transport from mass transit. This in turn has increased congestion thereby increasing fuel cost and travel time cost. Use of electricity in transport sector has the potential to reduce use of fossil fuels. Emission inventories were developed and real time exhaust emissions were studied. Study of travel pattern of commuters and various modes of road transport revealed that use of mass transit over personalized transport was a better choice as far as energy conservation and pollution mitigation is concerned. Driving cycles (DCs) were effective in estimating energy consumption and emissions. Development of regional DCs revealed the variations in driving characteristics over the regions and exposed the need to modify the DCs based on which emission norms for the country have been formulated.

During the review process, it was observed that not much literature is available related to energy consumption in passenger transport in road transport sector of West Bengal. This study aimed at addressing this void by estimating specific energy consumption pattern for different passenger transport vehicles in selected locations of West Bengal. Also, as the transport sector has been undergoing a change based on phasing out of older vehicles, introduction of new vehicles with better emission standards, introduction of electric vehicles and use of cleaner fuels like LPG, it became imperative to analyze the performance of these vehicles in real world driving conditions.

In order to address this scenario, this study also developed regional DCs for buses and 4Ws to establish a driving pattern for these vehicles which was unavailable till now.

Abbreviations

2Ws	Two Wheelers
4Ws	Four Wheelers
AAGR	Average Aannual Growth Rate
ARDL	Autoregressive Distributed Lag
ARM	Administrative Rules and regulation Management
ATI	Additional Tax Increase
AVL	Advanced Vehicle Location
BAU	Business As Usual
BEVs	Battery Electric Vehicles
BIO	Biodiesel Vehicles
BRT	Bus Rapid Transit
BS-IV	Bharat Stage IV
BUPTCM	Beijing urban passenger transport carbon model
CAGR	Compounded Annual Growth Rate
CAPEX	Capital Expenditure
CDM	Clean Development Mechanism
CH_4	Methane
CNG	Compressed Natural Gas

CO	Carbon Monoxide
CO_2	Carbon Dioxide
CP	Comprehensive Policy
CPR scenario	Comprehensive Scenario
DBDC	Delhi Bus Driving Cycle
DC	Driving Cycle
e2Ws	Electric Two Wheelers
e3Ws	Electric Three Wheelers
EBEC	Electric Bus Energy Consumption
e-BRTS	Electric Bus Rapid Transit System
eBus	Electric Bus
eCars	Electric Cars
EEI	Energy Efficiency Improvement
EU	European Union
EVs	Electric Vehicles
GDP	Gross Domestic Product
GHG	Green House Gas
GTP	Green Transportation Projects
HC	Hydro Carbon
HEL	High Engine Load
HEV	Hybrid Electric Vehicles

ICE	Internal Combustion Engine
IDC	Indian Driving Cycle
kNN	k Nearest Neighbor
LEAP	Long-range Energy Alternatives Planning
LEL	Low Engine Load
MAE	Mean Absolute Error
MAPE	Mean Absolute Percentage Error
MIDC	Modified Indian Driving Cycle
Mtoe	Million Tonnes Oil Equivalent
NGV	Natural Gas Vehicles
NMT	Non Motorized Transport
NMVOC	Non-Methane Volatile Organic Compounds
NO_x	Oxides of Nitrogen
OPEX	Operational Expenditure
Pb	Lead
PDPT	Priority to Development of Public Transport
PEMS	Portable Emission Measuring System
PEV	Promoting Electric Vehicle
PKE	Positive Kinetic Energy
PKM	Passenger Kilometer
PM	Particulate Matter

REF scenario	Reference Scenario
RF	Random Forest
RMSE	Root Mean Square Error
RPM	Respirable Particulate matter
SBCA	Social Benefit Cost Analysis
SO_2	Sulphur dioxide
SPM	Suspended Particulate Matter
SPV	Solar Photo Voltaic
TCO	Total Cost of Ownership
TDM	Travel Demand Management
TKM	Tonne kilometer
TMOTEC	Transportation Mode-Technology-Energy-CO_2
TP	Technical Progress
TTW	Tank-To-Wheel
VI	Vulnerability Index
VKT	Vehicle Kilometers Travelled
WTW	Well-To-Wheel

Chapter 3

Study on Energy Consumption Pattern in Road Transport in Kolkata and Selected Regions of West Bengal

3.1 Introduction

Energy is popularly known as the ability to do work. In other words, in order to perform work, some amount of energy is consumed. Thus, in order for a vehicle to move from one location to another, its engine consumes energy (diesel or petrol in case of internal combustion engine (ICE) vehicles) and generates rotational motion, which is then transmitted to the wheels of the vehicle. Before studying the consumption pattern, it is important to familiarize with the concept of energy consumption and specific energy consumption. Sections 3.1.1 and 3.1.2 aims at describing the concepts briefly.

3.1.1 Energy Consumption:

Considering a modern day conventional ICE vehicle that runs on diesel or gasoline/petrol, energy is consumed for running the engine of the vehicle, operating accessories and onboard equipments such as music system, lighting systems, alarm system etc. Apart from propulsion and accessory requirements, heating, ventilation and air-conditioning (HVAC) unit of the vehicle, is a necessity depending upon ambient conditions. Among the public mode of passenger transport, HVAC is present in case of air-conditioned buses (AC buses), selected cabs and taxis. In personalized mode, 4Ws posses the same. Energy consumption of a vehicle is majorly impacted by the operation of HVAC units. Energy consumed in context of this particular study is derived directly from rate of fuel consumption of the concerned vehicle. Fuel consumption rate for a particular vehicle is defined as the amount of fuel consumed by the vehicle to move a distance of 1 km and is expressed in terms of liters per kilometer (l/km). Correspondingly, energy consumption can be calculated based on the calorific value of the fuel.

Considering an ICE vehicle running on liquid fuel, if the vehicle move from point A (odometer reading x_1 km) to point B (odometer reading x_2 km), the distance covered AB is ($x_2 - x_1$) km or D km. Let the amount of fuel consumed while moving this distance be ‘y’ l. Therefore fuel consumption rate (f_c) can be calculated as shown in equation 3.1.

$$f_c = \frac{y}{(x2-x1)} = \frac{y}{D} \qquad \text{l/km}$$

D = Distance covered by the vehicle (km) (3.1)

Theoretically energy consumed for running a vehicle can be expressed as shown in equation 3.2.

$$\text{Energy Consumption rate } (E_v) = \text{Energy consumed by engine and accessories } (E_e) + \text{Energy consumed by HVAC unit } (E_{HVAC}) \quad (3.2)$$

If the vehicle HVAC is not operated, as in case of vehicles devoid of such systems, or where the system is kept inoperative, then E_{HVAC} is not taken into account, thus

$$E_v = E_e \quad (3.3)$$

Now, let calorific value of fuel type z is CV_z expressed in kWh/l.

Therefore energy consumption rate (E_v) corresponding to f_c can be calculated as shown in equation 3.4.

$$E_v = f_c \times CV_z \text{ kWh/km} \quad (3.4)$$

In other words, energy consumed by a vehicle or energy consumption rate of the vehicle is equal to the amount of energy that is obtained by burning same amount of fuel which is needed by the vehicle to move a distance of 1 km.

Now, interactions with vehicle owners and operators revealed that most people associated with mass transit vehicles are least concerned about energy consumption or environmental pollution from vehicular emissions. The only reason most vehicle owners get pollution under control (PUC) certificate for their vehicles is to prevent themselves from getting fined by the traffic police. These people are more concerned about the mileage of their vehicles. Mileage of a vehicle is described as the distance that a vehicle can travel at the expense of 1 unit of fuel. For example, in case of a diesel fueled ICE vehicle, mileage is distance moved using 1 l of diesel. Therefore better mileage of a vehicle means less money spent on fuel expenses. However, a closer look can reveal the fact that mileage, energy consumption, and vehicular emissions are interrelated. Lesser energy consumption by a vehicle means better mileage and hence lesser vehicular emissions.

3.1.2 Specific Energy Consumption:

Different types of vehicles have different passenger carrying capacity. Based on type of vehicle, passenger carrying capacity may depend on seating capacity or a combination of seating and standing capacity both. Seating capacity is fixed by the vehicle manufacturer. No proper specification is available for standing capacity. For example, survey data showed that motorcycle can carry 2 passengers, an auto rickshaw can carry 5 passengers, a car can carry 5 passengers, and a bus can carry at least 27 passengers based on seating capacity. If standing is allowed for bus, survey suggests that it can carry 50 passengers. The mileage of a motorcycle, an LPG auto rickshaw, a car and a bus as per a random survey data set is found to be approximately 40 km/l, 17 km/l, 12 km/l and 3 km/l respectively. If anyone wants to judge these vehicles based on their mileage, then a motorcycle seems to be the best option. However, if energy consumption is considered, the values corresponding to the mileages of the above mentioned vehicles comes out to be 0.235 kWh/km, 0.392 kWh/km, 0.833 kWh/km, and 3.333 kWh/km respectively. Therefore, considering the seating capacity, it can be said that a motorcycle consumes 0.235 kWh of energy to transport 2 passengers by a distance of 1 km. Similarly, an auto rickshaw, a car and a bus consumes 0.392 kWh, 0.833 kWh, and 3.333 kWh to move 5, 5 and 27 passengers respectively by a distance of 1 km. In order to compare energy consumption of different vehicles with different passenger carrying capacities, energy consumed by the corresponding vehicle to move 1 passenger by a distance of 1 km is calculated. This is called the specific energy consumption. It is expressed by the unit of kWh per passenger per kilometer or kWh per passenger km (kWh/pkm).

Now, it has to be kept in mind that every time a vehicle plies the streets, it necessarily does not commute the same number of passengers corresponding to its seating capacity. Therefore calculating specific energy consumption based on seating capacity of the vehicle may not yield accurate results. Hence ‘passengers per vehicle’ (also referred as Equivalent Passenger Load) data was obtained from a study by Reddy and Balachandra (2012). According to this study, different types of vehicles were assigned a certain passenger per vehicle value. For example, in case of a bus, the value was 50 and in case of a taxi, the value was 3. These values have been used to calculate specific energy consumption further in this study.

Equation 3.5 shows the formula for calculation of specific energy consumption.

$$E_{sp} = \frac{E_v}{p} \qquad \text{kWh/pkm}^{*} \qquad (3.5)$$

where, E_{sp} = Specific Energy Consumption
E_v = Energy consumption rate of the vehicle
p = equivalent number of passengers
*pkm denotes passenger kilometers

The comparison of energy consumption and specific energy consumption calculated based on seating capacity of the vehicle has been shown in Table 3.1. It can be seen that although motorcycle consumed minimum energy to travel a distance of 1 km, specific energy consumption was least for auto rickshaw. Again although bus consumed maximum energy to travel a distance of 1 km, maximum specific energy consumption was attributed to car. Clearly the value for specific energy consumption varied with respect to number of passengers transported.

Table 3.1: Comparison of energy consumption and specific energy consumption

Vehicle	**Mileage (km/l)**	**Energy Consumption Rate (kWh/km)**	**Seating Capacity**	**Specific Energy Consumption (kWh/pkm)**
Motorcycle	40	0.235	2	0.118
Auto Rickshaw (LPG)	17	0.392	5	0.078
Car	12	0.833	5	0.167
Bus	3	3.333	27	0.123

3.2 Studies on Consumption Pattern:

A two phased plan was devised in order to execute the study of energy consumption pattern in road transport sector. First phase of the study involved survey based data collection which could reveal an overall energy consumption scenario in the sector for public transit vehicles. The second phase of the study involved a closer look at the performance of these vehicles at real time driving conditions. This chapter deals with the first phase of the study whereas the second phase has been dealt with in subsequent chapter. Various steps taken in executing first phase of the plan has been discussed in the following sections.

3.2.1 Choice of Locations:

The state of West Bengal is characterized by a vast range of geographical variations, extending from the coastal areas in the south to the hilly regions in the north. On one hand there is hustle of busy Tier I cities, whereas on the other hand there is comparatively slow moving and peaceful villages and rural areas. Total number of registered motor vehicles in the state recorded as on 31st March 2019 was 7446000 out of which 712000 were transport vehicles and 6733000 vehicles were non transport vehicles (Road Transport Year Book 2017-18 & 2018-19). In accordance with the locations, the transportation scenario of these places changes too. Keeping this in mind, four different locations were chosen: Kolkata, Durgapur, Mal Bazar and Bakkhali as shown in Figure 3.1(a-d). Kolkata is a Tier I city and Durgapur is a Tier II city. Mal Bazar and Bakkhali represent more of a rural area. The following section briefly describes the locations chosen for survey.

3.2.1.1 Kolkata:

Located within 22°37´ and 22°30´ North latitudes and 88°23´ and 88°18´ East longitudes, the city extended over an area of 185 square km and had a population of 4.4 million (District Census

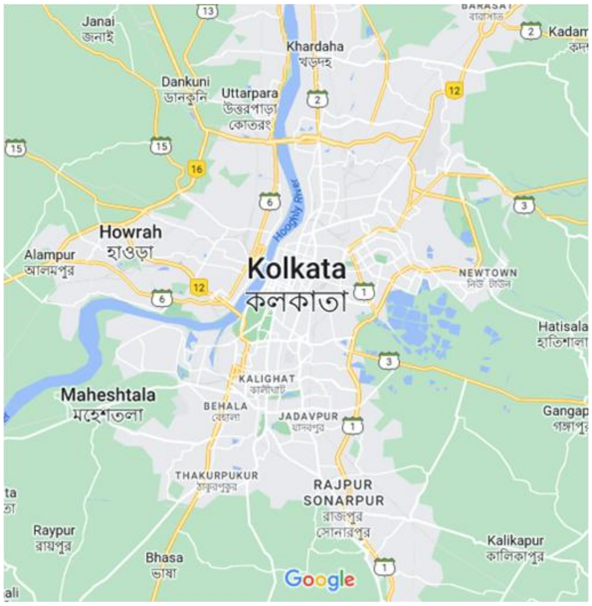


Figure 3.1(a): Map of Kolkata

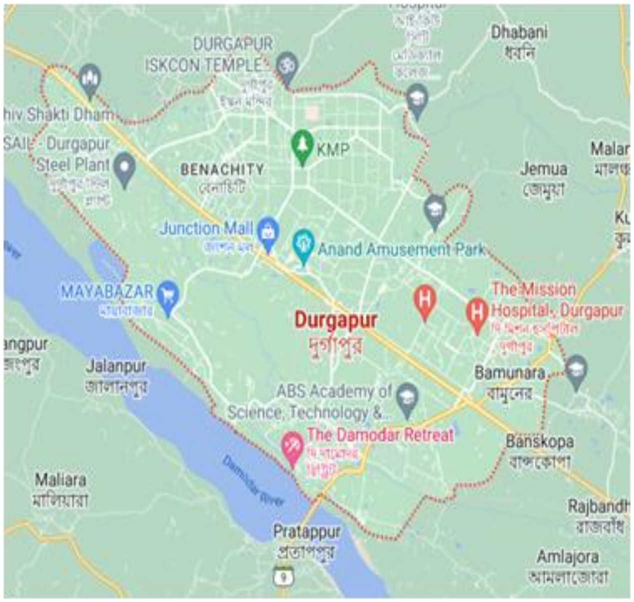


Figure 3.1(b): Map of Durgapur

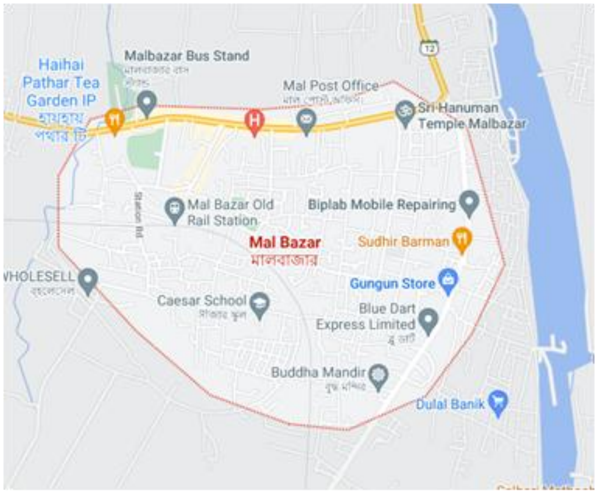


Figure 3.1(c): Map of Mal Bazar

Figure 3.1(d): Map of Bakkhali

Handbook Kolkata). In recent times some of the surrounding areas have been included withinKolkata and is now popularly known as Greater Kolkata. As on 2020, Kolkata extends over 206.1 square km and has a population of 14.9 million people (https://www.google.com/search?q=kolkata+demography&rlz=1C1VDKB_enIN987IN987&oq=kolkata+demography&aqs=chrome..69i57j0i22i30j0i390l2.7961j0j7&sourceid=chrome&ie=UTF-8 ref 18). Mass transit via road is mainly dependent on buses, taxis and auto rickshaws.

On an average weekday, road based mass transport cater to 57.88% of the total passenger load (Dey, 2015). Of the total vehicle fleet strength, personalized vehicles enjoy major share (84.61%) as compared to public vehicles (15.39%) (Dey, 2015). The city recorded 0.8 million registered motor vehicles as on 31st March 2019 out of which 0.1 million are transport vehicles and 0.7 million are non transport vehicles (Road Transport Year Book 2017-18 & 2018-19). As on 31st March 2019, the city reported 6189 buses, 52354 taxis and 20760 passenger auto rickshaws plying the streets (Road Transport Year Book 2017-18 & 2018-19).

3.2.1.2 Durgapur:

The industrial city of Durgapur is located at 23°48´ North latitudes and 87°32´ East longitudes and comes under Paschim Bardhaman district of West Bengal (Ghosh and Tah, 2015). It covers an area of 157 square km and has a population of 3 million people (https://en.wikipedia.org/wiki/Durgapur#Geography). Most preferred mode of mass transit is auto rickshaws and private mini buses. Auto rickshaws run in different routes from City Center to different parts of the city. Buses operate in different routes from Prantika to station terminus. Apart from these there are Ola cabs and Ambassador Taxis that ply the city streets. Totos are also found, although they are restricted in certain areas within the city limits.

3.2.1.3 Mal Bazar:

Mal Bazar is a sub-divisional town under Jalpaiguri district, located at 26°85´ North latitudes and 88°75´ East longitudes, in the northern parts of West Bengal (https://en.wikipedia.org/wiki/Malbazar#Geography). It extends over an area of 3.5 square km and has a population of 25218 people (https://en.wikipedia.org/wiki/Malbazar#Geography). This place is known more as a gateway to Dooars which is a spot of tourist attraction. Most preferred mode of mass transit among the local people is Toto and Tata Magic. However, with the introduction of Toto, Tata Magic is losing its popularity. This is because riding a Toto is cheaper as compared to its counterpart. Apart from these, there are buses operated by private bus owners as well as government bodies such as North Bengal State Transport Corporation (NBSTC). NBSTC buses normally operate on inter-city routes. Vehicles like Mahindra Bolero are mostly used by tourists for their transportation.

3.2.1.4 Bakkhali:

Bakkhali is a coastal village in Kakdwip sub-division of South 24 Parganas district in West Bengal. It is located at 21°33´ North latitudes and 88°15´ East longitudes and has a population of 2180 people (https://en.wikipedia.org/wiki/Bakkhali, Census 2011). Local people rely on Toto and buses for their transportation. Bakkhali, being a tourist attraction, attracts lot of tourists, who prefer to travel in their own cars and motorcycles.

3.2.2 Choice of Vehicles:

The next step in this plan was choice of vehicles that will be studied. As already mentioned earlier, passenger transport vehicles, mainly buses, 4W and 3W were chosen for this particular study.

Among all the segments, buses are the most popular mode of public road transport, contradicting their reduced share among vehicle population. In 2020 both public and private buses contributed to 17% of motorized passenger activity (India Transport Report Moving India to 2032 Volume

III). There are different types of buses plying the streets which can be categorized based on length, availability of air-conditioning, and fuel used. Most abundantly available buses belong to 9m and 12m category. Both the types of buses have been chosen for this particular study. Based on the availability of air-conditioning, both AC and Non AC buses have been studied. Based on fuel used, both diesel driven ICE buses and eBuses that run on electricity has been kept under the scope of this study. Specifications for different types of buses surveyed have been shown in Table 3.2.

4W contributed to approximately 9% of total passenger traffic and 27% of total energy consumed in passenger transport, in 2020 (India Transport Report Moving India to 2032 Volume III). Growth in the number of 4W can be contributed to rising income levels along with demand for app based on-demand services. In the 4W segment, most commonly used commercial vehicles are taxis and cabs. In the city, people mostly use Ola / Uber cabs, and Ambassador Taxis. In the rural areas, cabs or taxis are not available. Vehicles like Tata Magic and Mahindra Bolero are preferred more in these areas. These four types of vehicles were studied in this research work. Specifications for different types of 4W surveyed have been shown in Table 3.3.

In the 3W segment, both LPG and diesel auto rickshaws were studied since they form major part of Intermediate Public Transport (IPT). LPG auto rickshaws are allowed to ply within the city limits. However, diesel auto rickshaws can be found only in the outskirts of the city. Apart from these, Toto (also known as electric rickshaw or E-rickshaw) and Vano (also known as mechanized van rickshaws) were also studied. Toto is a very popular vehicle in 3W EV segment and is widely used in the city outskirts and rural areas.

Vano is the popular name of mechanized van rickshaws that are normally assembled with low cost diesel fueled engines meant for irrigation purpose. Like Toto, these vehicles are also found in the city outskirts and rural areas. Specifications for different types of 3W surveyed have been shown in Table 3.4.

Images of different types of vehicles that have been studied during the course of this research work have been shown in Figure 3.2.

Table 3.2: Specifications for buses surveyed

Specifications	**ICE 9m Non AC Bus**	**ICE 12m Non AC Bus**	**ICE 9m AC Bus**	**ICE 12m AC Bus**	**9m Electric Bus**	**12m Electric Bus**
Fuel Type	Diesel	Diesel	Diesel	Diesel	Electricity	Electricity
Gross Vehicle Weight	10200 kg	10200 kg	16200 kg	16200 kg	10200 ± 300 kg	17800 ± 500 kg
Engine / Motor Rating	92 kW @ 2600 rpm	3LNGDICR engine, 100.52 kW	5660 cc, 117.82 kW @ 2400 rpm	Volvo D7E, 7140 cc, 216.25 kW	245 kW	245 kW
Maximum Torque	390 Nm @ 1000 – 2200 rpm	360 Nm	550 Nm @ `1200 – 1900 rpm	1200 Nm	3000 Nm	3000 Nm
Fuel Tank / Battery Capacity	120 L	160 L	239 L	220 L	124 kWh	186 kWh
Seating Capacity	41+D	51+D	31+D	32+D	31+D	40+D
Vehicle Length	9750 mm	10120 mm	9860 mm	12290 mm	9200 mm	11900 ± 100 mm

Table 3.3: Specifications for surveyed 4W

Specifications	**Ambassador Taxi**	**Ola / Uber Cabs**	**Tata Magic**	**Mahindra Bolero**
Fuel Type	Diesel	Diesel	Diesel	Diesel
Gross Vehicle Weight	1554 kg	1415 kg	1600 kg	2215 kg
Engine / Motor Rating	1817 cc 55.16 kW @ 5000 rpm	1248 cc 55.93 kW @ 4000 rpm	702 cc 11.93 kW @ 3200 rpm	1498 cc 55.90 kW @ 3600 rpm
Maximum Torque	130 Nm @ 3000 rpm	190 Nm @ 2000 rpm	38 Nm @ 2000 rpm	210 Nm @ 1600 – 2200 rpm
Fuel Tank	42 L	42 L	30 L	60 L
Seating Capacity	4+D	4+D	7+D	6+D
Vehicle Length	4325 mm	3995 mm	3790 mm	3995 mm

Table 3.4: Specifications for surveyed 3W

Specifications	**LPG Auto Rickshaw**	**Diesel Auto Rickshaw**	**Toto**	**Vano**
Fuel Type	LPG	Diesel	Electricity	Diesel
Gross Vehicle Weight	687 kg	780 kg	190 kg	16200 kg
Engine / Motor Rating	236.2 cc 7.42 kW @ 5000 rpm	599 cc 7kW	0.85 kW	3.24 kW / 2.94 kW @ 2600 rpm
Maximum Torque	17.65 Nm @ 3550 rpm	23.5 Nm	-	-
Fuel Tank / Battery Capacity	20.6 L	10.5 L	48V 100 Ah	10.5 L
Seating Capacity	3+D	3+D	4+D	8+D
Vehicle Length	2635 mm	2940 mm	2850 mm	3900 mm

Figure 3.2: Images of surveyed vehicles

3.2.3 Research Methodology:

In order to study the energy consumption pattern, a primary survey was conducted. This involved physical interviews of people associated with operating these vehicles; such as drivers, conductors, intermediate operators, mechanics, vehicle owners, commuters and fuelling station workers. Approximately 300 people were interviewed in different bus terminus, taxi stands, auto rickshaw stands and fuelling stations. A pilot survey was conducted, based on which the questionnaire (ANNEXURE I) for the final survey was prepared. First phase of the survey was conducted in the city of Kolkata and its outskirts. After successfully completing the survey in Kolkata, the study was further extended for the regions of Durgapur, Mal Bazar and Bakkhali.

Buses and auto rickshaws in West Bengal operate in fixed routes whereas taxis and cabs are exceptions. These routes are determined by the government and permits are issued for the same. A vehicle having a permit to ply a particular route is not allowed to operate in other routes. A route can be defined as the path that the vehicle follows from its starting point to its destination. The starting point and the destination points are normally referred to as stands, for example bus stands for buses and auto stands for auto rickshaws. The journey from the starting point to the destination point is called a half trip. The to and fro journey of a route is referred to as a trip. Based on the number of trips per day, the total distance per day is calculated.

Route distance in case of vehicles plying in particular routes, or total distance travelled in case of taxis and cabs were obtained from the vehicle odometer reading where it was available. However the odometers for most vehicles do not function properly. In such cases, route distances mentioned by the vehicle drivers were verified by riding a motorcycle in the same route and noting down its odometer readings.

As far as fuel consumption is concerned, government operated buses in Kolkata do not use private fuelling stations for refueling. Government bus depots have their own fuelling stations that are inaccessible to general public and private operators. Hence documentation pertaining to fuel consumed was unavailable for government buses. Fuel consumption data for government buses was collected based on verbal communications with bus drivers and conductors. For other vehicles, fuel consumption data was obtained from fuelling station receipts and verbal communications, which were then cross checked while interviewing fuelling station workers.

Passenger capacity for different vehicles was calculated based on number of passenger seats available. Driver's seat was not taken into account and was mentioned as "+D" along with the passenger capacity. Normally, vehicles belonging to the same category have same passenger capacity. However, some buses in the same category have different number of passenger seats based on their manufacturers. In such cases, passenger capacity taken into account for this study reflects the seating capacity of majority of the vehicles surveyed under that particular category.

Calorific values for diesel and LPG and equivalent passenger load were referred from literature as have already been mentioned earlier (Majumdar, 2022, Reddy and Balachandra, 2012). Sample calculation of specific energy consumption from collected data has been shown in the following section.

3.2.3.1 Sample Calculation:

Let, d_i = distance of route *i* in km, also known as half trip distance.

n = number of trips per day

Therefore, total distance travelled per day by vehicle *j* in route *i* can be calculated as

$$D_{ji} = 2 \times n \times d_i \tag{3.6}$$

If fuel consumed by vehicle *j* in route *i* be *l* liters per day, and calorific value of the fuel be *c* kWh per liter, then energy consumption rate by that vehicle in that particular route can be calculated as

$$e_{ji} = \frac{l \times c}{D_{ji}} \tag{3.7}$$

If equivalent passenger load for the vehicle be p_{eq}, then specific energy consumption for vehicle *j* in route *i* can be calculated as

$$s_{ji} = \frac{e_{ji}}{p_{eq}} \tag{3.8}$$

Energy consumption for vehicle type *v* can be calculated as

$$E_v = {\sum_j e_{ji}}/{m} \tag{3.9}$$

where, m = number of vehicles surveyed.

Specific Energy consumption for vehicle type v can be calculated as

$$S_v = {\sum_j s_{ji}}/{m} \tag{3.10}$$

3.2.4 Results and Discussions:

Information obtained during the survey revealed a picture about how these vehicles operate in their respective locations. It can be observed that the transportation demand of different vehicle changes with location. For example, if buses are considered, Kolkata has a wider variety of buses plying the city streets as compared to Mal Bazar, Durgapur or Bakkhali. AC buses are operated by government bodies only in Kolkata and Durgapur. There are no private AC buses for intra city travel. If total distance travelled per day is considered, in case of Kolkata, the range varies between 89.60 km to 192.50 km, whereas for the other locations this range increases substantially. For Mal Bazar, this range varies between 130 km to 240 km, for Durgapur 200 km to 420 km, and for Bakkhali 288 km. One of the main reasons behind this can be the fact that Kolkata having a larger area has lager number of intra city bus routes with smaller route distances and more trips per bus. The average half trip distance for bus route in Kolkata is 22 km and average number of trips per day is 3.75. In case of Durgapur, there are intra city buses with average half trip distance of 20 km running 5 trips per day, and there are inter-city buses also which run a single trip per day having source-destination length of 210 km. In case of the other locations, most of the buses that ply are long distance buses having larger route distance (half trip distance varying between 60 km to 144 km) and lesser number of trips (1 to 2 trips per day). In case of fuel consumption, 9m Non AC ICE buses reported a slightly better mileage of 3.96 km/l as compared to 12m Non AC ICE buses (3.32 km/l). 9m and 12m AC ICE buses reported a mileage of 1.5 km/l and 1.6 km/l respectively.

After buses, the most popular mode of passenger road transportation is 3W like auto rickshaws, Toto and Vano. In Kolkata, auto rickshaws ply both inside the city as well as outskirts; although some of the city streets are off limits. Both LPG and diesel fueled auto rickshaws are found here. However diesel auto rickshaws are not allowed within the city limits due to pollution reasons. In the outskirts, Toto have become more popular recently as compared to Vano. Vano had the advantage of carrying more passengers as compared to the other 3Ws but Toto is more cost effective. Both auto rickshaws and Toto can be seen plying the streets of Durgapur. However, in Mal Bazar and Bakkhali, Toto is the only 3W that can be seen on streets. Total distance travelled per day by auto rickshaws in Kolkata and Durgapur was reported to be about 100 km and 62.5 km respectively. Corresponding mileage was recorded as 18.71 km/l and 21 km/l respectively for LPG auto rickshaws. For diesel auto rickshaws, the mileage was 21 km/l. Distance covered per day for Toto in all locations varied between 70 km to 75 km, whereas Vano reported merely 36 km per day with a mileage of approximately 30 km/l.

Taxis and cabs have always been the choice of people belonging to a higher income category (Das Gupta, 2014). In Kolkata, old Ambassador Taxis can still be found plying city streets. Ola / Uber cabs have become very popular recently as compared to taxis mainly because of its ease of accessibility at a few clicks of a smart phone. Also commuters do not have to face issues like refusal by drivers to go to a certain location or payment of extra fare, which was very common in case of old taxis. Both Ambassador Taxi and Ola cabs can be found in Durgapur. However, unlike Kolkata there are no Uber cabs. Taxis and cabs in Kolkata ply intra-city but in Durgapur, these vehicles ply intra-city as well as inter-city routes. A taxi or a cab travels an average distance of 155 km per day in Kolkata whereas in case of Durgapur, this distance comes down to 85 km per day. Mileage for these vehicles was reported to vary between 10 km/l to 14 km/l. In case of Mal Bazar , in 4W segment, local people rely on Tata Magic to fulfill their commuting needs. Apart from these, there is Mahindra Bolero. These vehicles are used more by tourists as compared to local people. Distance covered per day by these vehicles vary within a range of 75 km to 250 km. Mileage of Tata Magic and Mahindra Bolero was reported to be 8.5 km/l and 11 km/l respectively. Bakkhali has a different scenario as far as 4W is concerned. Local people used to travel by Tata Magic but with the introduction of Toto, these vehicles lost its popularity and disappeared from the streets. Tourists use 4W which are mainly private vehicles or are cars hired from outstation. Hence these 4W were kept out of the scope of this study.

Data obtained from the survey were analyzed, calculations were done, and final results were tabulated as shown in Table 3.5-3.7. Graphs obtained from the calculations better demonstrate the energy scenario as shown in Figures 3.3-3.11. Figure 3.3 shows the variation in energy consumption of ICE Non AC buses in different locations. For all the locations, energy consumed by 9m bus was less as compared to 12m bus. For Kolkata, 9m buses consumed 2.6 kWh/km of energy as compared to 12m buses that consumed 3.10 kWh/km. Maximum deviations in energy consumption was observed in Mal Bazar (2.09 kWh/km and 3.64 kWh/km) whereas Durgapur reported minimum deviation (2.5 kWh/km and 2.86 kWh/km). In Bakkhali, 12m buses consumed 2.86 kWh/km. 9m buses were not found in Bakkhali. Figure 3.5 showed the energy consumption variation between AC and Non AC buses. It was observed that 9m Non AC ICE buses consumed less energy as compared to its 12m counterpart. However, in case of AC ICE bus, the scenario reversed. The consumption for eBuses was same (0.97 kWh/km). The reason behind this can be attributed to the fact that when energy consumption data for eBuses were obtained from the charging data sheet available from the depot, the data sheet had no record of whether the vehicle charged belonged to 9m category or 12m category. Therefore for this particular study, energy consumption data was assumed to be same of both 9m and 12m eBuses.

Figure 3.4 shows the variation in specific energy consumption for Non AC ICE buses in different locations. For Kolkata, the values for 9m and 12m buses are 0.0597 kWh/pkm and 0.0621 kWh/pkm respectively. Mal Bazar showed maximum deviation in specific energy consumption (0.0480 kWh/pkm for 9m and 0.0727 kWh/pkm for 12m). Durgapur reported almost similar specific energy consumption for 9m and 12m buses (0.0574 kWh/pkm and 0.0571 kWh/pkm) and Bakkhali reported 0.0570 kWh/pkm for 12m bus. Data for 9m bus was not available. Figure 3.6 shows the variation in specific energy consumption for AC and Non AC buses. It was observed that specific energy consumption for 9m Non AC ICE bus (0.0597 kWh/pkm) was less as compared to its 12m counterpart (0.0621 kWh/pkm). In case of AC ICE bus the scenario reverses and 9m bus reports higher specific energy consumption (0.1531 kWh/pkm) as compared to 12m bus (0.1248 kWh/pkm). Similar scenario can be observed for AC eBuses (0.0223 kWh/pkm for 9m bus and 0.0194 kWh/pkm for 12m bus). Data for Non AC eBuses are unavailable since all the electric buses plying in West Bengal are fitted with AC.

Table 3.5: Survey Results for Buses

Location	Vehicle type	Fuel	Distance covered per day (km)	Fuel consumption per day (liter)	Passenger Capacity	Calorific Value of fuel (kWh/l)	Energy consumption (kWh/km)	Equivalent passenger load	Specific Energy Consumption (kWh/pkm)
Kolkata	9m Non AC	Diesel	157.43	39.70	27+D	10.00	2.60	43.55	0.060
	9m AC	Diesel	89.60	59.73	27+D	10.00	6.67	43.55	0.153
	12m Non AC	Diesel	148.57	45.46	31+D	10.00	3.10	50.00	0.062
	12m AC	Diesel	192.50	120.00	33+D	10.00	6.24	50.00	0.125
	9m AC	Electricity	132.08		31+D		0.97	43.55	0.022
	12m AC	Electricity	132.08		40+D		0.97	50.00	0.019
Mal Bazar	9m Non AC	Diesel	130.00	27.20	30+D	10.00	2.09	43.55	0.048
	12m Non AC	Diesel	240.00	87.27	45+D	10.00	3.64	50.00	0.073
Durgapur	9m Non AC	Diesel	200.00	50.00	27+D	10.00	2.50	43.55	0.057
	12m Non AC	Diesel	420.00	120.00	45+D	10.00	2.86	50.00	0.057
Bakkhali	12m Non AC	Diesel	288.00	82.29	45+D	10.00	2.86	50.00	0.057

Table 3.6: Survey Results for 3W

Location	Vehicle type	Fuel	Distance covered per day (km)	Fuel consumption per day (liter)	Passenger Capacity	Calorific Value of fuel (kWh/l)	Energy consumption (kWh/km)	Equivalent passenger load	Specific Energy Consumption (kWh/pkm)
Kolkata	Auto rickshaw	LPG	101	5.41	4+D	6.67	0.359	1.75	0.205
	Auto rickshaw	Diesel	100	4.76	6+D	10.00	0.476	2.63	0.181
	Toto	Electricity	75		4+D		0.075	1.75	0.043
	Vano	Diesel	36	1.20	8+D	10.00	0.333	3.50	0.095
Durgapur	Auto rickshaw	LPG	62.5	2.98	4+D	6.67	0.318	1.75	0.181
	Toto	Electricity	72		4+D		0.075	1.75	0.043
Mal Bazar	Toto	Electricity	70		4+D		0.075	1.75	0.043
Bakkhali	Toto	Electricity	96		4+D		0.075	1.75	0.043

Table 3.7: Survey Results for 4W

Location	**Vehicle type**	**Fuel**	**Distance covered per day (km)**	**Fuel consumption per day (liter)**	**Passenger Capacity**	**Calorific Value of fuel (kWh/l)**	**Energy consumption (kWh/km)**	**Equivalent passenger load**	**Specific Energy Consumption (kWh/pkm)**
Kolkata	Ambassador Taxi	Diesel	150.00	12.25	4+D	10	0.817	3	0.272
	Ola / Uber Cab	Diesel	161.67	12.44	4+D	10	0.762	3	0.254
Mal Bazar	Tata Magic	Diesel	75.00	8.82	9+D	10	1.176	3	0.392
	Mahindra Bolero	Diesel	250.00	22.73	8+D	10	0.909	5	0.182
Durgapur	Ambassador Taxi	Diesel	75.00	6.82	4+D	10	0.909	3	0.303
	Ola Cab	Diesel	95.00	7.31	4+D	10	0.769	3	0.256

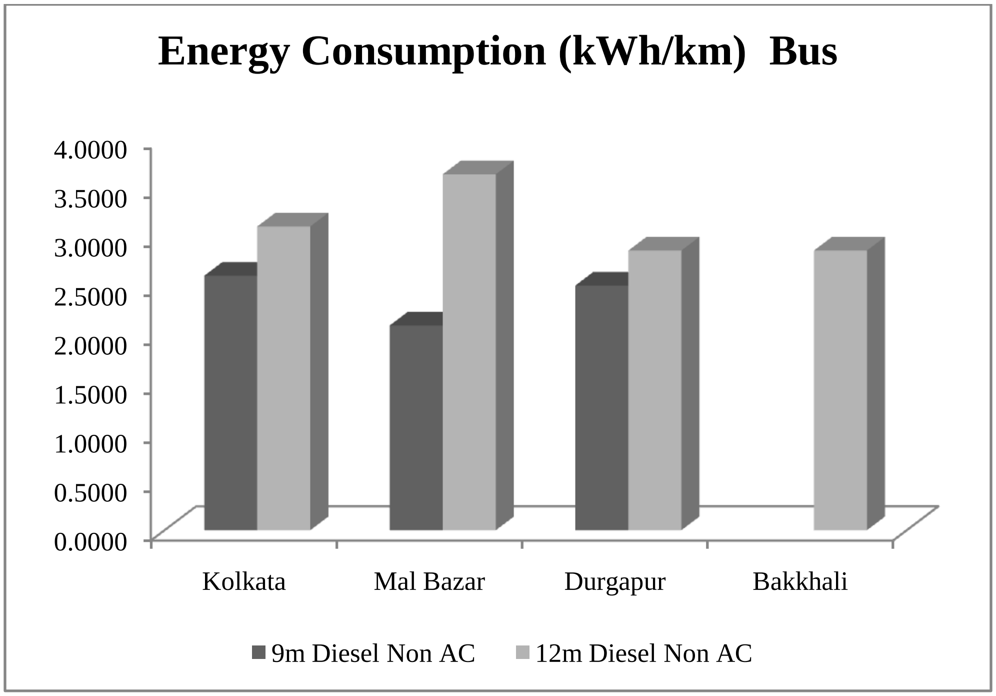


Figure 3.3: Energy Consumption for Non AC Bus in different locations

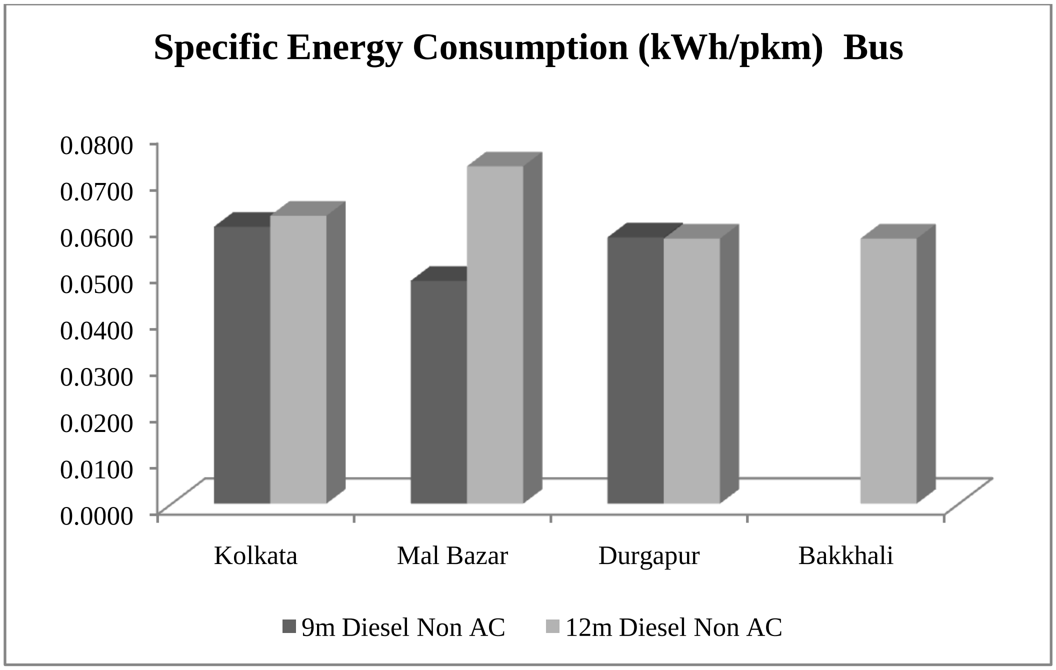


Figure 3.4: Specific Energy Consumption for Non AC Bus in different locations

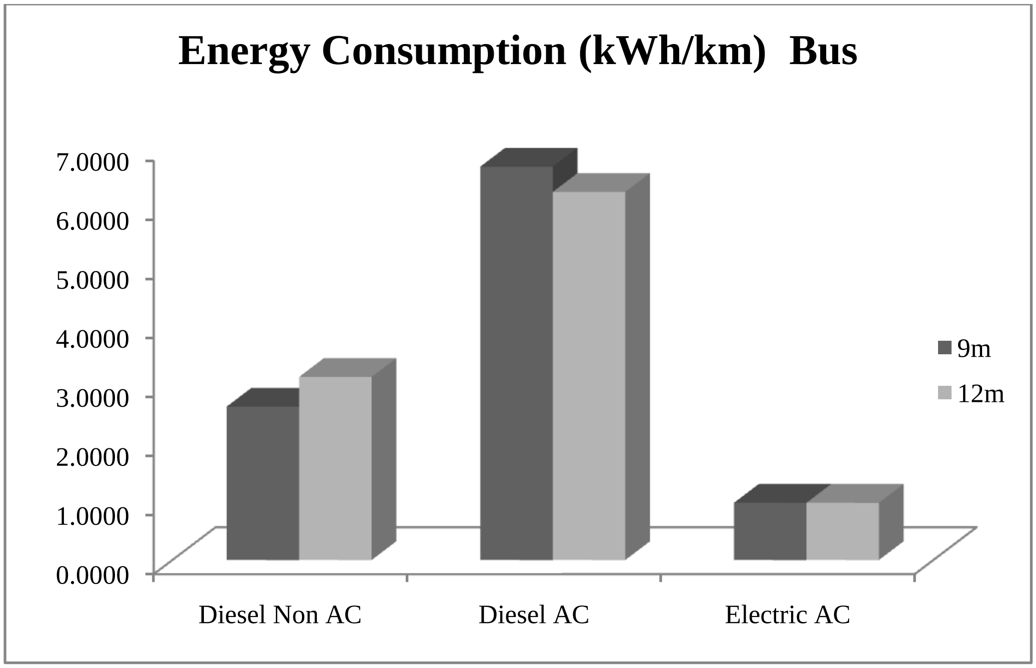


Figure 3.5: Energy Consumption comparison for 9m and 12m bus

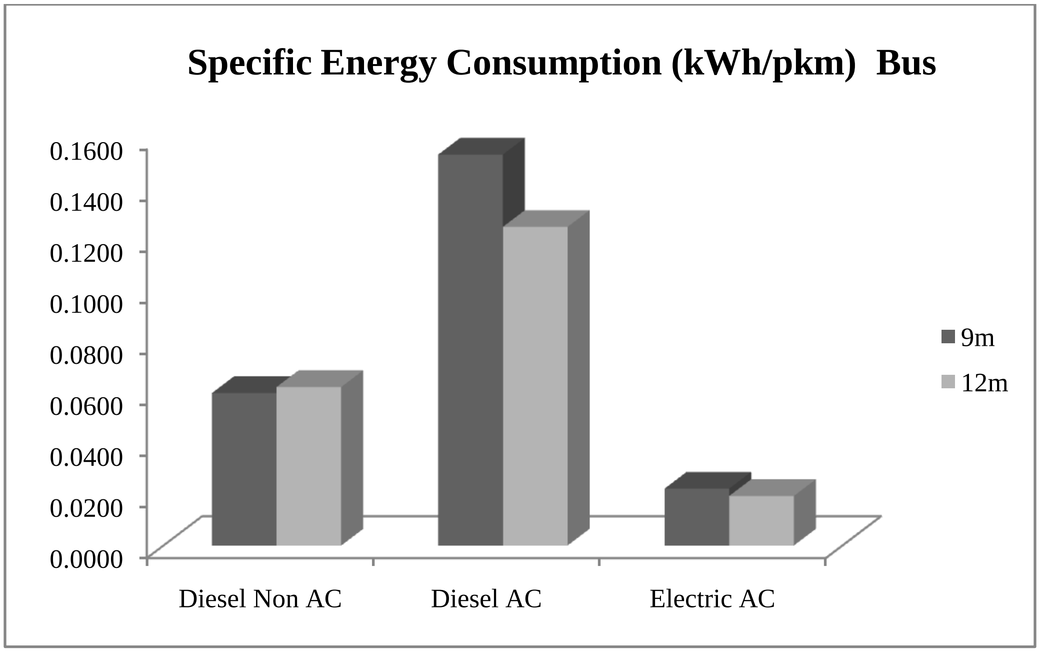


Figure 3.6: Specific Energy Consumption comparison for 9m and 12m bus

Figures 3.7-3.9 describes the energy scenario for 3W. Figure 3.7 show how the energy consumption and specific energy consumption varied for LPG auto rickshaws in Kolkata and Durgapur. It was observed that energy consumption rate in case of Kolkata was more (0.3592 kWh/km) as compared to Durgapur (0.3176 kWh/km). Similar scenario was observed in case of specific energy consumption (0.2053 kWh/pkm for Kolkata and 0.1815 kWh/pkm for Durgapur). Auto rickshaws were not found in Mal Bazar and Bakkhali. Hence data was unavailable for these locations.

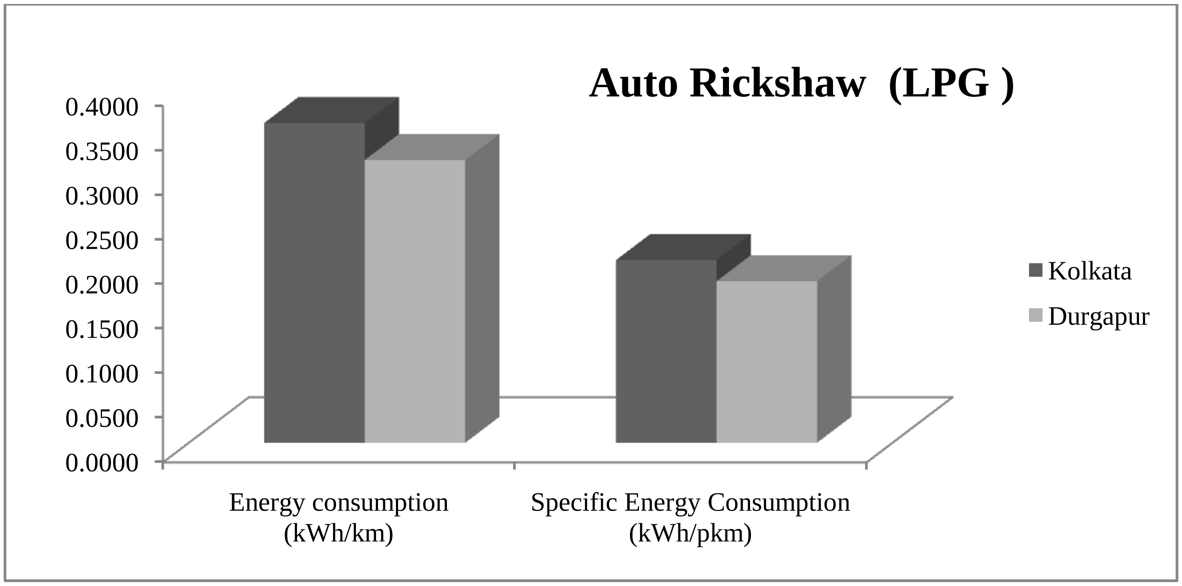


Figure 3.7: Variations in Energy and Specific Energy Consumption for LPG Auto rickshaws in Kolkata and Durgapur

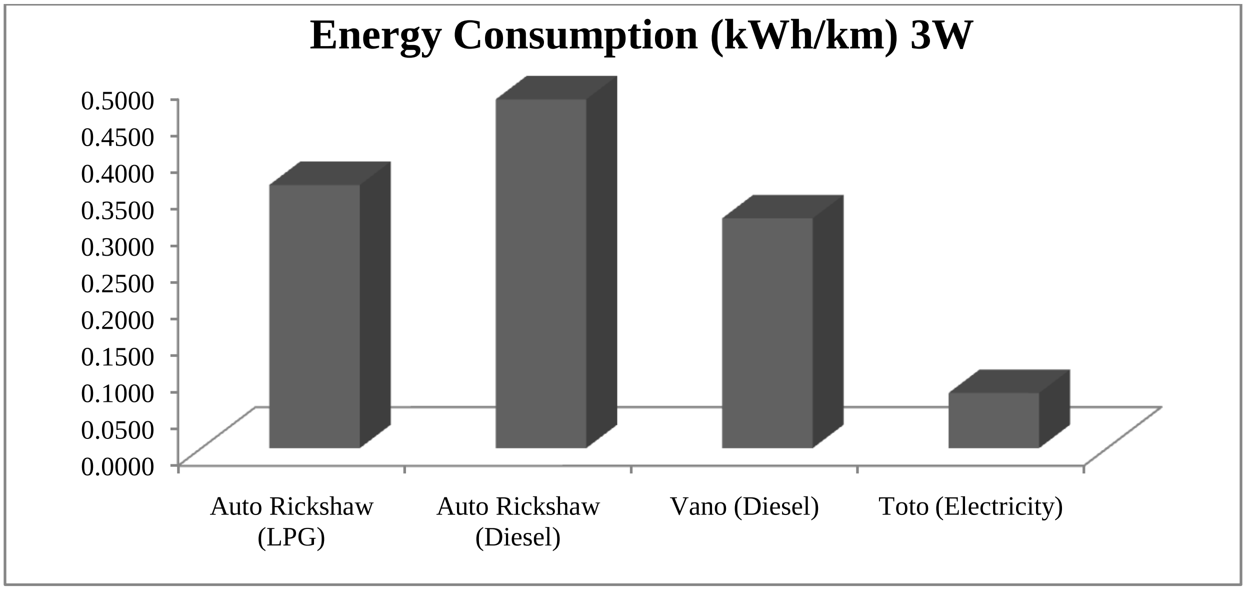


Figure 3.8: Energy Consumption for 3W

Figure 3.8 shows the variation in energy consumption for different types of 3W surveyed under the scope of this study. It was observed that maximum energy was consumed by diesel fueled auto rickshaws (0.4762 kWh/km) while Toto consumed minimum (0.0753 kWh/km). Figure 3.9 shows the variation in specific energy consumption for the above mentioned vehicles. It was observed that Toto had the least consumption (0.0430 kWh/pkm) while LPG fueled auto rickshaws reported maximum consumption (0.2053 kWh/pkm).

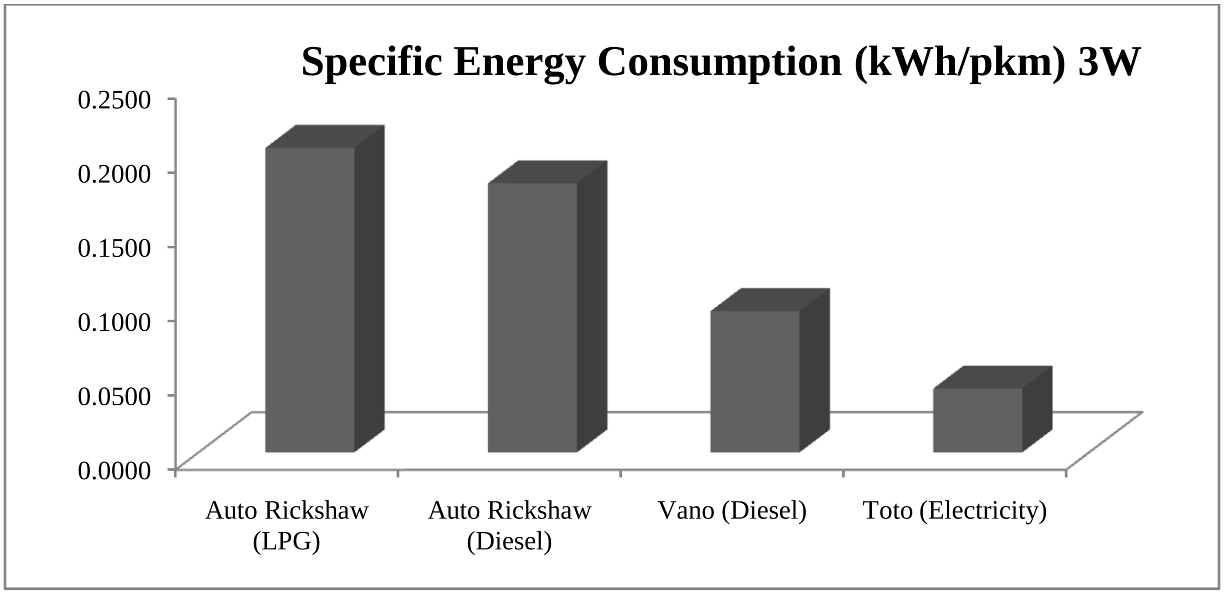


Figure 3.9: Specific Energy Consumption for 3W

Figures 3.10 and 3.11 shows location based variation in energy and specific energy consumption for Ambassador Taxi and Ola / Uber cabs. Results showed similar trend in both energy and specific energy consumption.

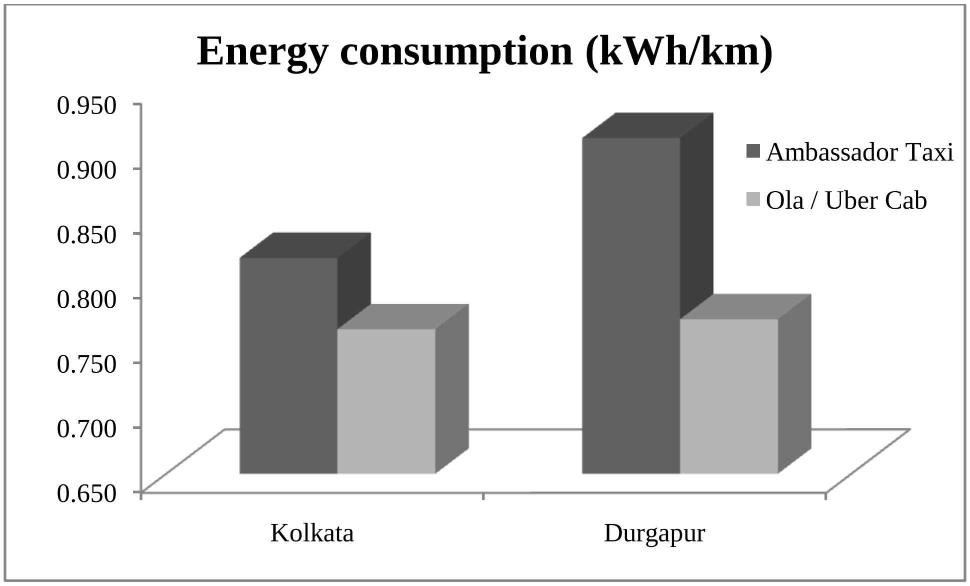


Figure 3.10: Location based variation in Energy Consumption for 4W

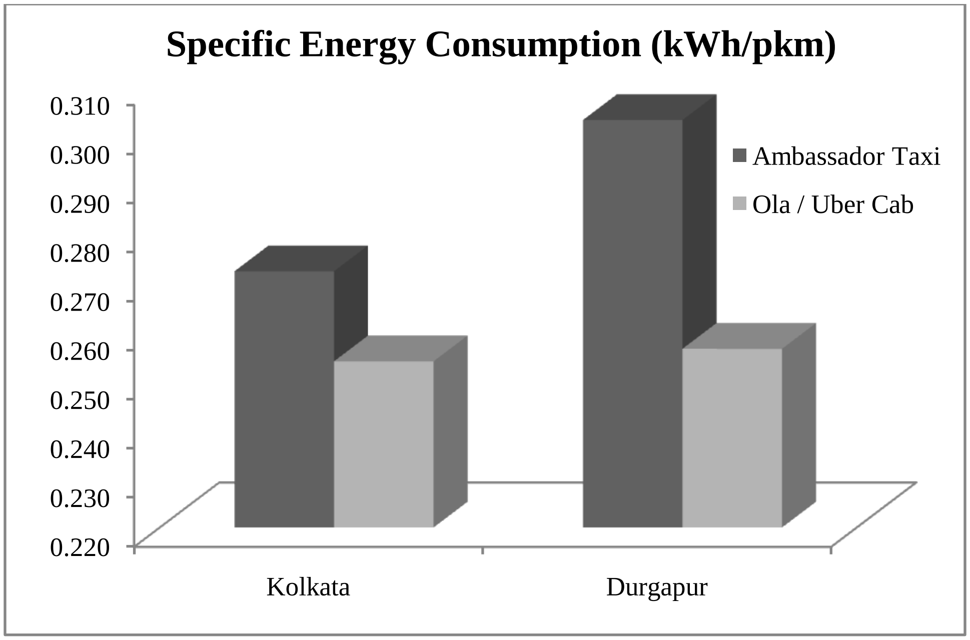


Figure 3.11: Location based variation in Specific Energy Consumption for 4W

It was observed that consumption for Ambassador Taxis was more in Durgapur (0.909 kWh/km and 0.303 kWh/pkm) as compared to Kolkata (0.817 kWh/km and 0.272 kWh/pkm). Ola / Uber cabs reported similar consumption for both locations (0.762 kWh/km and 0.254 kWh/pkm for Kolkata: 0.769 kWh/km and 0.256 kWh/pkm for Durgapur).

Figures 3.12-3.13 describes overall energy scenario for 4W. It was observed that maximum energy was consumed by Tata Magic (1.176 kWh/km) whereas minimum energy was consumed by Ola/Uber Cabs (0.762 kWh/km). However in case of specific energy consumption, although Tata Magic reported maximum consumption (0.392 kWh/pkm), minimum consumption was reported by Mahindra Bolero (0.182 kWh/pkm).

Overall comparison of energy consumption and specific energy consumption for different vehicles surveyed for all the locations have been shown in Figures 3.14-3.15. Energy consumption pattern amongst non electric vehicles surveyed under the scope of this study shows that bus consumed more energy as compared to 4W and 3W, where 3W consumed the least (Figure 3.14).

Maximum energy consumption was reported by 9m diesel fueled ICE bus and minimum energy consumption was reported for Vano. However in case of specific energy consumption, Vano reported minimum consumption whereas Tata Magic reported maximum consumption (Figure 3.15).

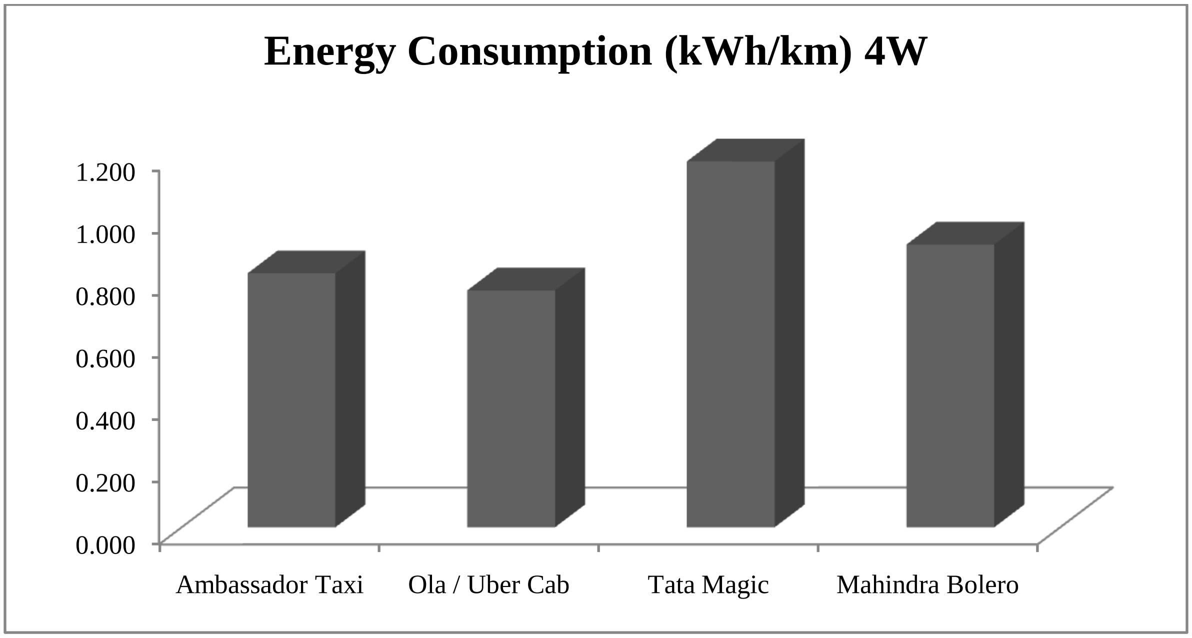


Figure 3.12: Energy Consumption for 4W

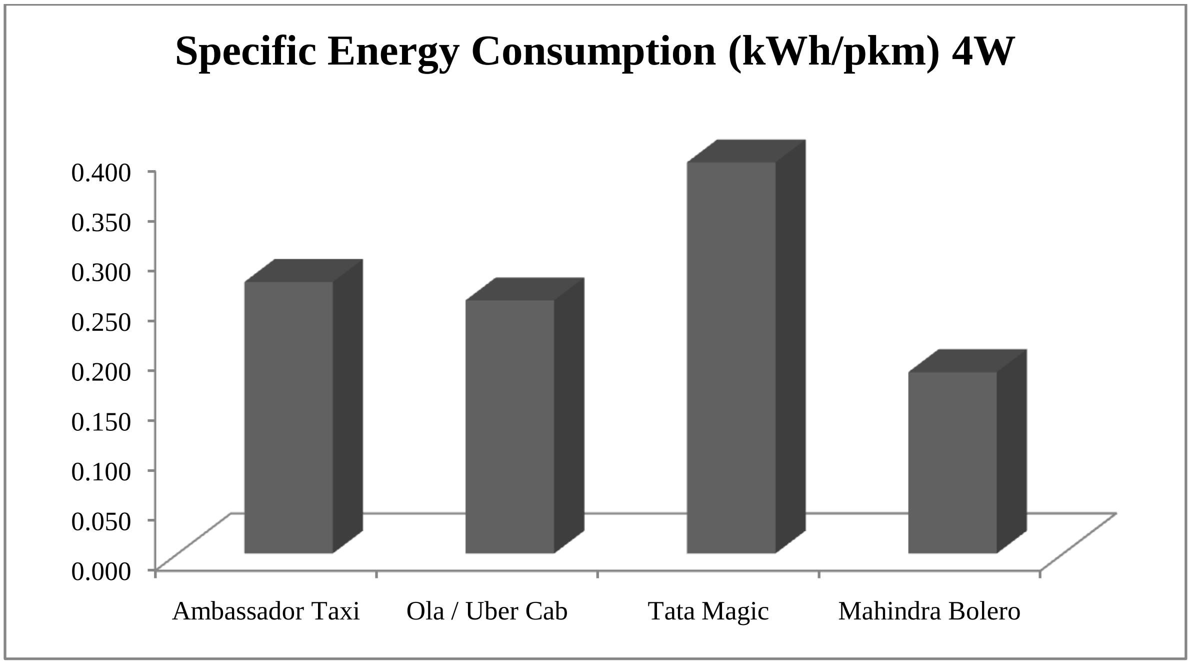


Figure 3.13: Specific Energy Consumption for 4W

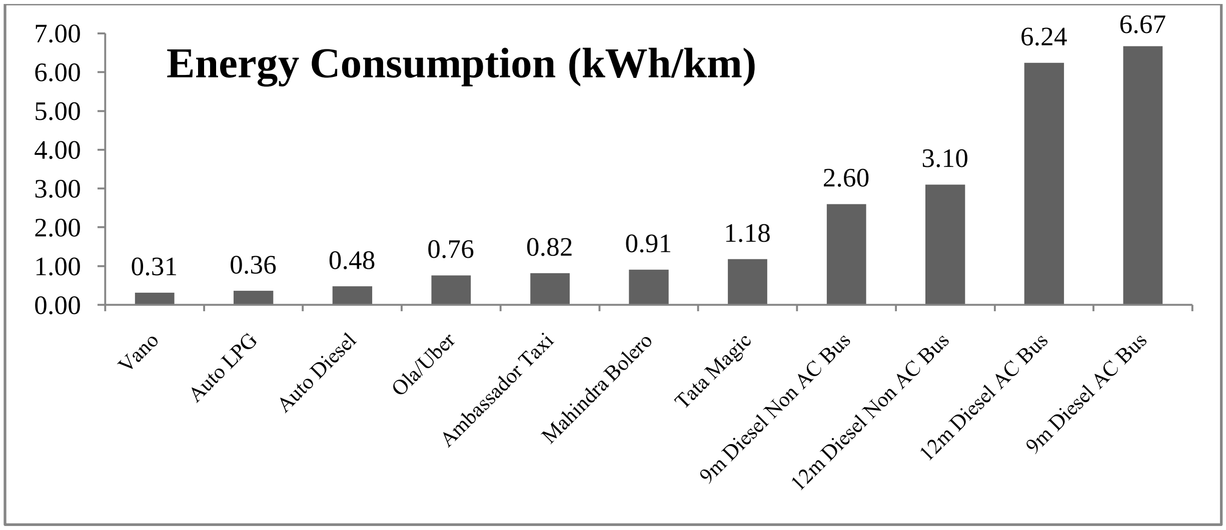


Figure 3.14: Energy Consumption for Non Electric Vehicles

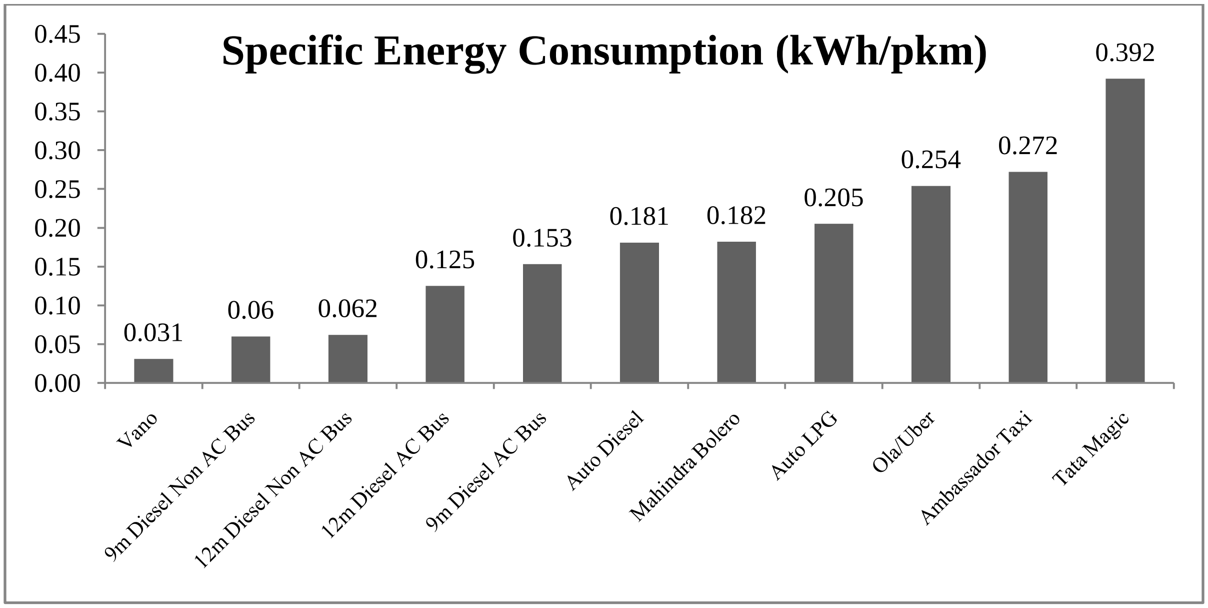


Figure 3.15: Specific Energy Consumption for Non Electric Vehicles

Figure 3.16 and 3.17 shows the energy consumption pattern and specific energy consumption amongst electric vehicles respectively. It was observed that Toto consumed least energy whereas both 9m and 12m eBuses consumed same amount of energy. As far as specific energy consumption is concerned, 12m eBus consumed least energy while Toto consumed maximum. Electric 4W are not used for commercial mass transit in any of the surveyed locations although it has recently impregnated private vehicle sector. Hence data for the same was unavailable.

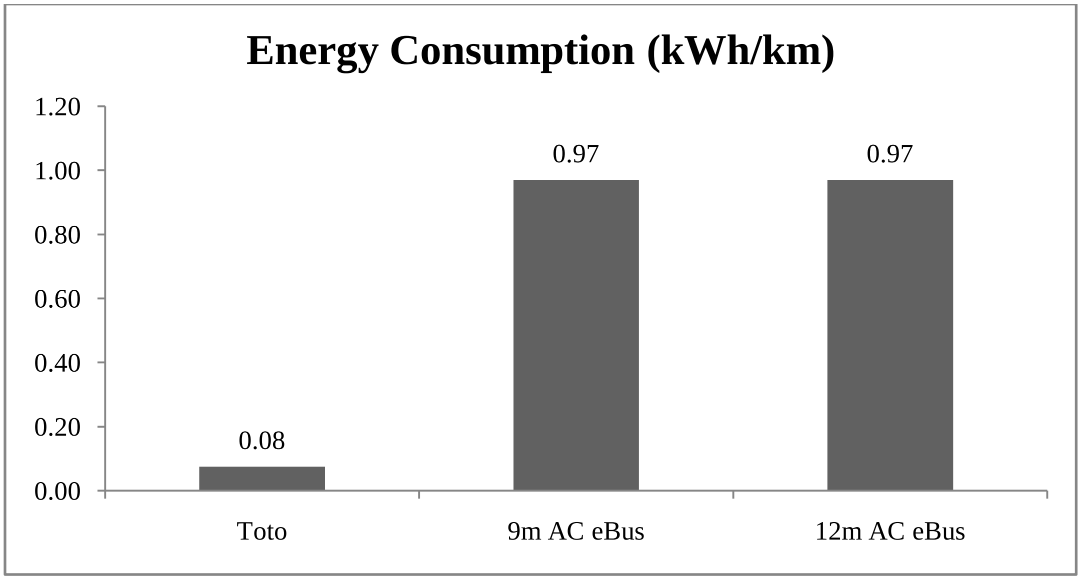


Figure 3.16: Energy Consumption for Electric Vehicles

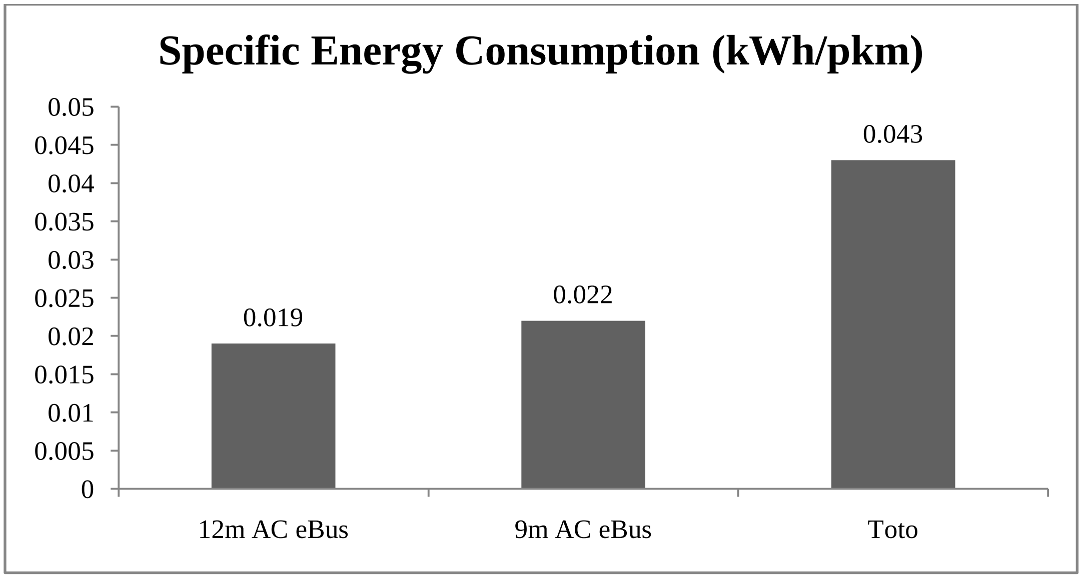


Figure 3.17: Specific Energy Consumption for Electric Vehicles

Interactions with survey respondents revealed crucial details pertaining to vehicle operation, vehicle maintenance and financial aspects. Government vehicles are operated and maintained by salaried government employees having fixed working hours and periodic offs. Each vehicle belongs to a particular depot where the vehicle undergoes maintenance and rests when not operated. These vehicles are refueled at specified fuel stations that are inaccessible to common people. Being salaried employees, the drivers and conductors of these vehicles are least bothered about the number of passenger being commuted. This in turn affects the revenue generated from this sector. Unlike government vehicle operators, private vehicle operators do not have fixed working hours. Average working hours per day for a driver or a driver conductor duo is approximately 15 hours. There are no weekly holidays. These people do not have fixed salaries and work on a “no work no pay” basis. For these people payment is directly dependent on number of passengers commuted. This often leads to irrational driving (unnecessarily slow or fast). Vehicles are operated relentlessly and do not have any maintenance schedule. Maintenance for these vehicles is on “need to” basis. New vehicles need lesser maintenance but older vehicles are forced to visit the repairing shop almost every month. Financial conditions are becoming worse day by day. Passenger fares for these vehicles have not increased proportionately over time (especially for private buses) despite the continuous rise in fuel price. Prices of vehicle spare parts as well as charges for mechanics have increased, thereby adding to operational expenses. Reductions in profit margins have made it difficult to pay the EMIs leading to an unsustainable situation. Most of the people are stuck in this profession in the absence of a better alternative.

3.3 Conclusion:

The survey revealed an overall picture of energy scenario in public transit sector of mentioned locations which has not been reported thus far in available literature. It was revealed that although vehicles with larger passenger carrying capacity consumed more energy as compared to smaller vehicles, the specific energy consumption or energy consumed per passenger for unit distance travelled is better for these vehicles as compared to the smaller ones in most cases. This establishes the fact that in order to conserve energy in transport sector, usages of vehicles like buses are a better choice as compared to 3W or 4W. Also it was observed that electric vehicles consumed much lesser energy as compared to the conventional vehicles using fossil fuels. This has been discussed in later chapters.

Apart from energy scenario, the survey revealed important information regarding the operating conditions of these vehicles, their maintenance schedules, and the financial aspects related to operating these vehicles. These factors are crucial and needs to be considered while planning for improvement of transport scenario and future developments in the sector. The survey also revealed that there are various other factors that can influence the energy consumption, for example traffic conditions, vehicle loading, driver behavior, etc. Now, all these factors get reflected in the driving pattern of the vehicles. In order to study this, an attempt was made to develop a driving cycle (DC). This part of the study has been discussed further in the next chapter.

Abbreviations:

3W	3 Wheeler
4W	4 Wheeler
AC	Air Conditioned
DC	Driving Cycle
E_v	Energy Consumed
E_e	Energy consumed by engine and accessories
E_{HVAC}	Energy consumed by Air conditioning
eBus	Electric Bus
EV	Electric Vehicle
ICE	Internal Combustion Engine
IPT	Intermediate Public Transport
kWh/pkm	Kilo Watt Hour per Passenger Kilometer
LPG	Liquefied Petroleum Gas
NBSTC	North Bengal State Transport Corporation
Non AC	Non Air Conditioned
PUC	Pollution Under Control

Chapter 4

Driving Cycle Development for Road Transport Vehicles in Kolkata and Estimation of Energy Consumption

4.1 Introduction:

Analysis of initial survey results revealed the necessity to have a closer look at the impact of various factors affecting the energy consumption scenario. There are different factors that can affect energy consumption of a vehicle. For example, a congested road condition will reduce the speed of the vehicles and increase the idling time thereby increasing energy consumption, whereas an uncongested road allows free movement of traffic thereby enabling comparatively lesser energy consumption depending on vehicle speed. Again, vehicle loading has a significant impact on energy consumption since an overloaded vehicle consumes more energy. Similarly, the mental and physical health of a driver influences the driving pattern and hence impacts energy consumption. Now, impact of all the factors gets reflected in the way in which the vehicle moves in the street. This can be interpreted by a driving cycle (DC), which is conventionally represented by a speed-time or a speed-distance curve for a vehicle moving from one point to another. DCs can be classified as synthetic or actual.

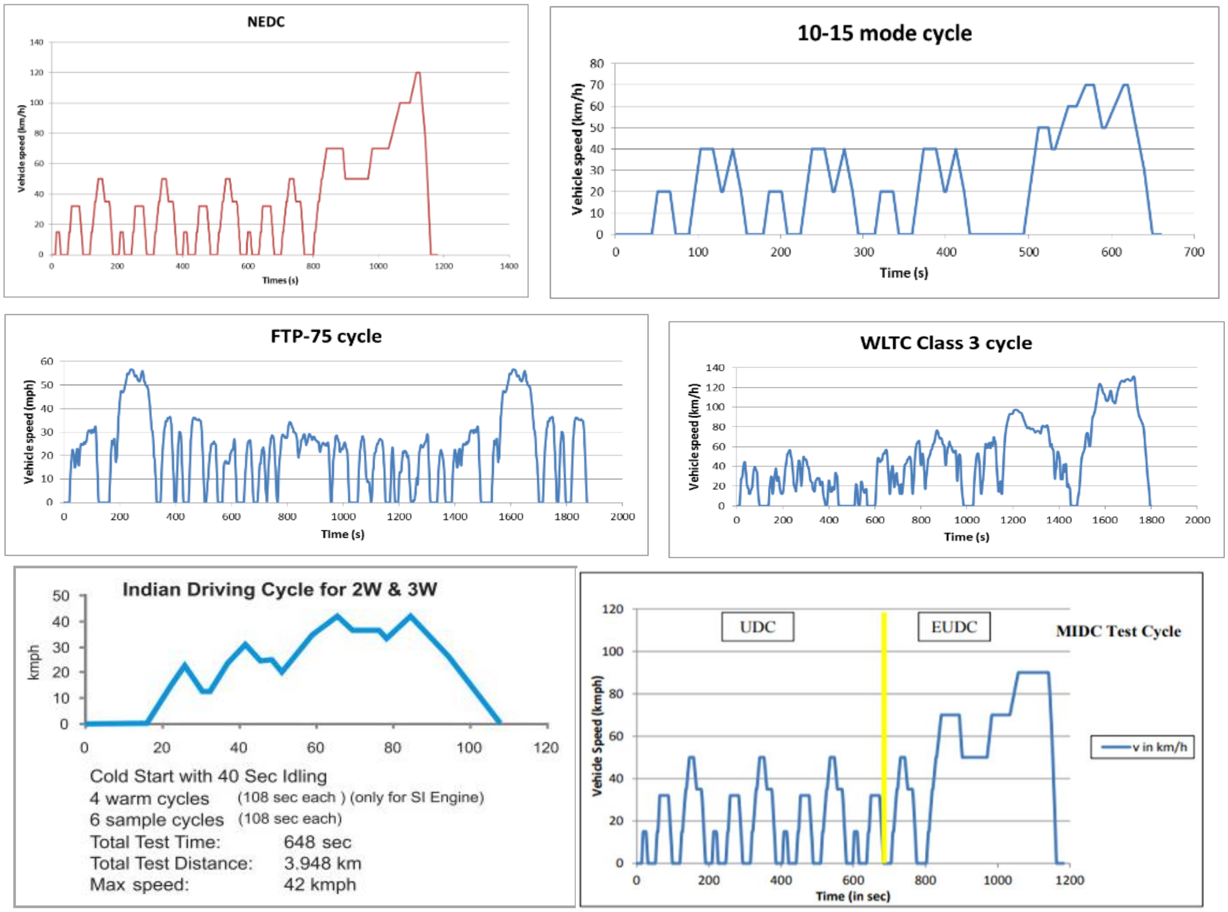


Figure 4.1: Available Driving Cycle Images (Source: Fotouhi and Montazeri, 2013)

A synthetic DC is based on constant acceleration and cruising phase whereas actual DC is based on real time on road data collection with the help of a test vehicle (Maurya and Bokare, 2012). A DC can be used to characterize the performance of a vehicle in order to derive its fuel consumption and emission patterns. Some of the popularly know DC are New European Driving Cycle (NEDC), Federal Test Procedure (FTP) 72, FTP 75, 10-15 Mode, World Harmonized Light Vehicle Test Cycle (WLTC), Indian Driving Cycle (IDC), and Modified Indian Driving Cycle (MIDC) as shown in Figure 4.1. (Fotouhi and Montazeri, 2013)

4.2 Methodology:

Traffic conditions vary based on locations and this in turn varies the vehicle performance and hence energy consumption and emissions. For example, European traffic conditions are different from the conditions in India. Hence NEDC will not be able to properly represent driving profile in India. Also different parts of India have different traffic conditions and hence the driving profile will vary accordingly. This shows the importance of developing regional DC. There are a few regional DCs available in India. Automotive Research Association of India (ARAI) has developed IDC, MIDC and Overall Bus Driving Cycle (OBDC). However since these DCs are based on constant speed and acceleration profiles, they are unable to properly reflect real world driving conditions (Maurya and Bokare, 2012). DC for Bus Rapid Transit System (BRTS) was developed in Delhi Metropolitan Regions by Kumar and Gupta (2011). Kamble et al. (2009) developed Urban DC for Pune, Nesamani and Subramanian (2011) developed intra-city bus DC in Chennai, and Yugendar et al. (2020) developed DC for Ludhiana. This chapter attempts at developing DC for buses and 4Ws (passenger cars) in Kolkata. Figure 4.2 show the steps involved in developing a DC. These steps have been discussed further in subsequent sections.

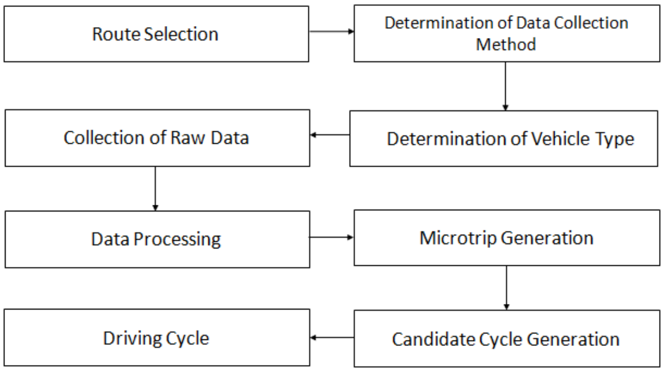


Figure 4.2: Steps involved in DC generation

4.2.1 Route Selection:

The first step in the process of DC generation was route selection. City roads through which the vehicles ply, vary widely based on factors such as road width, location of the road (arterial roads, sub arterial roads, etc.), traffic composition plying the streets (motorized traffic only, motorized and non-motorized traffic). All these factors affect the driving conditions and hence the DC. Although the impact of these factors was not studied individually, the routes for this particular study were chosen in such a way not studied individually. The routes for this particular study were chosen in such a way that the overall impact of the different types of roads on the traffic flow can be reflected in the DC. The routes on which following study has been conducted are given in Table 4.1.

Table 4.1: Routes used for data collection

Route	Distance (km)
Baghbari - TCS Gitanjali Park	28.98
Baguiati College More - Abhishikta (Kalikapur)	15.40
Bakultala - Jadavpur Gate 3 (via Rabindra Sadan)	17.10
Bakultala - Jadavpur Gate 3 (via Tollygunge)	10.70
Behala Chowrasta - Baguiati	29.60
Behala Chowrasta - Bangur	22.40
Behala Chowrasta - Jadavpur University Gate 4	16.40
Behala Tram Depot - Jadavpur University Gate 4	21.60
Chinar Park - TCS Gitanjali Park	10.56
Dhakuria - Salt Lake Karunamoyee	15.70
Iris Hospital - Baghbari	10.42
Jadavpur University Gate 3 - Haraharitala	11.10
Janakalyan - 8B Bus Stand	9.70
Sakherbazar - Jadavpur University Gate 3	10.60
Salt Lake Karunamoyee - Chinar Park	13.65
TCS Gitanjali Park - Iris Hospital	23.00

4.2.2 Data Collection:

Next step in the process of developing DC was data collection. Data collection has two aspects: data collecting equipment and data collecting method. Normal practices to collect vehicle trajectory data include use of mobile devices, Global Positioning System (GPS) or On Board

Diagnostics (OBD) (Maurya and Bokare, 2012, Kumar et al., 2011). In this study, initially ‘My Tracks’ app installed in android based smart phone was used to record trajectory data. In order to test reliability of data collected, a 150cc motorcycle was boarded by a rider and pillion rider duo and after turning on the application, a stretch of 10 km distance was travelled. The application was operated by pillion rider and simultaneously starting time, stoppage time, idling time, etc were recorded manually. The data collected revealed that idling time for the surveyed route was not getting reflected properly. Same process was repeated with another smart phone based application called ‘Geo Tracker’. The results were compared again and it was observed that although results for Geo Tracker were better that My Tracks, it still did not reflect the actual scenario properly. Finally a GPS data logging system as shown in Figure 4.3 was fabricated with ATmega 2560 microcontroller (µC) and Adafruit Ultimate GPS logger. It had a sampling rate of 10 Hz and hence data obtained from this logger represented the actual conditions much better than the mobile based applications used earlier. (Majumdar, 2022).

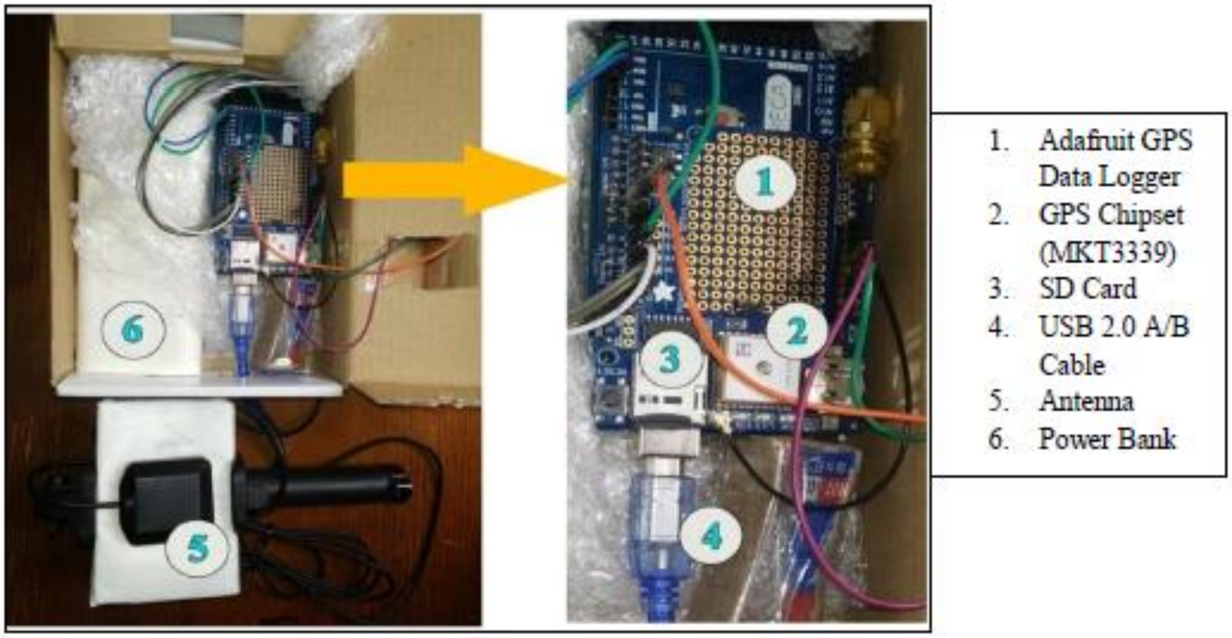
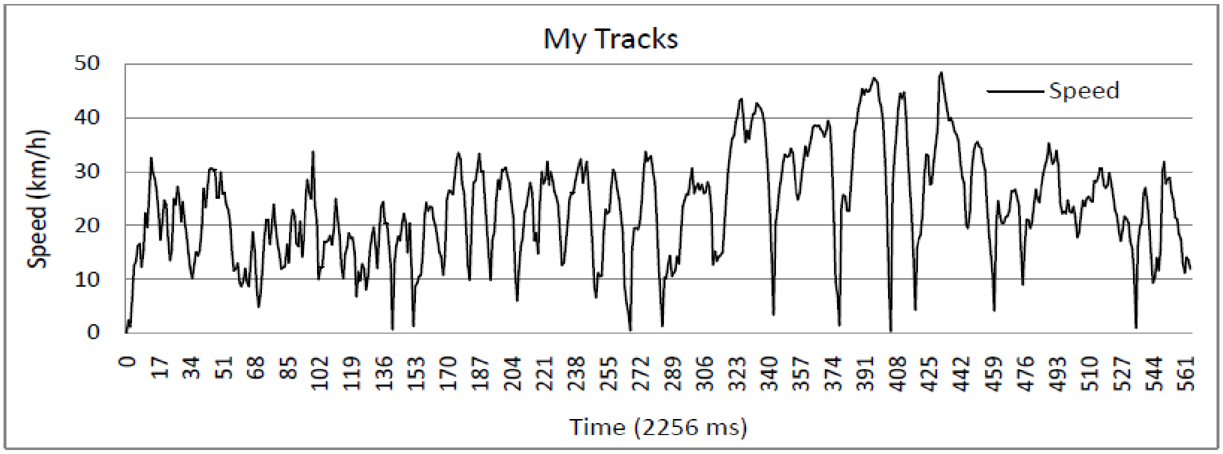


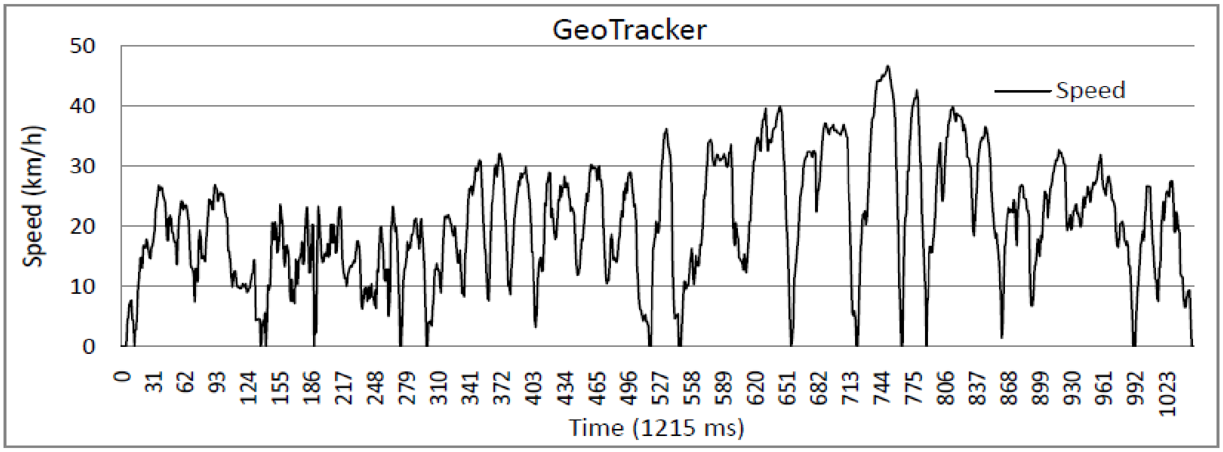
Figure 4.3: GPS data logger and its components.

In order to test the reliability of this data, a test route was chosen and the data logger was operated simultaneously with My Tracks and Geo Tracker applications. Results revealed that ATmega data logger was more accurate as compared to the other applications. Figure 4.4 shows the routes traced by the applications and the data logger. Speed-time plots obtained from data recorded by the devices have been shown in Figure 4.5 (a-c). It can be clearly observed that accuracy of the ATmega based data logger was much better as compared to smart phone applications.

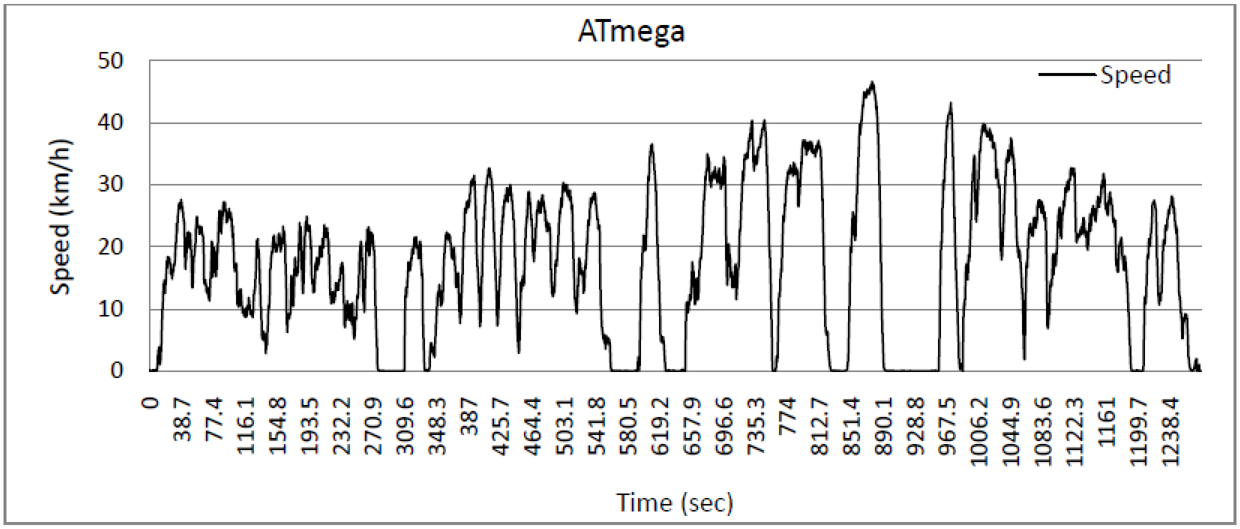
Figure 4.4: Routes traced by smart phone applications and fabricated data logger



(a)



(b)



(c)

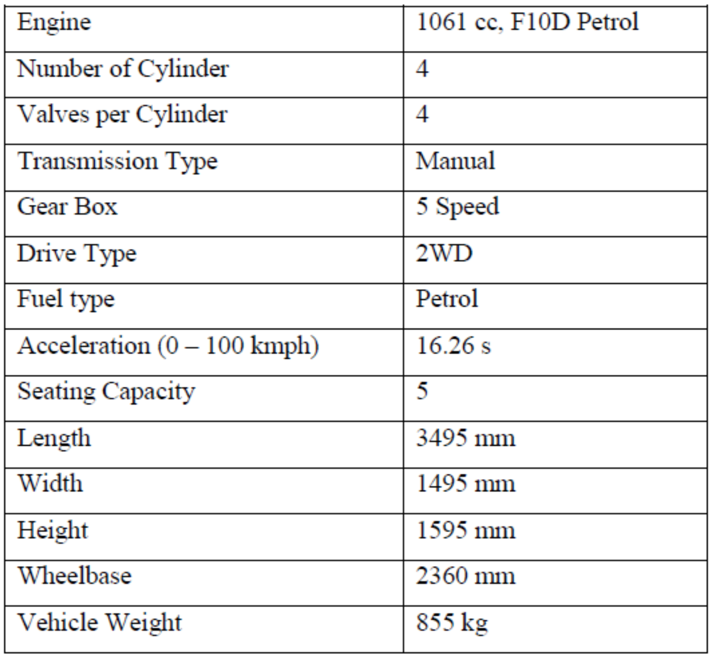
Figure 4.5 (a-c): Speed-time plots for smart phone applications and fabricated data logger

After selection of data logging equipment, choosing suitable data collection method was the next step. Literature review revealed that there were mainly two methods of data collection: onboard method and the car chase method. In case of onboard method, data acquisition system is placed on the vehicle that is being tracked whereas in case of car chase method the data acquisition system is placed on a test vehicle that follows the vehicle being tracked from a safe distance. Both the methods have advantages and disadvantages. For example, onboard method can reflect data better since data acquisition device in on the vehicle itself. However in case of car chase method there is a delay since driver of test vehicle has to observe the vehicle being tracked and then react to it. Hence errors can creep in. Again in case on onboard method, route selection is very important, because if not selected properly, the data obtained will not be able to reflect variations properly. Car chase method is a better choice to incorporate variations in driving patterns. Another advantage of car chase method is that it requires less resource and is much cost effective (Kamble et al., 2009).

For this particular study, DC was developed for buses and 4W. DC for 3W has already been developed by Majumdar (2022). In developing DC for bus, car chase method was followed using a two wheeler as mentioned earlier in this chapter. DC was developed for both ICE bus and eBus. Car chase method can be risky and prone to accidents in case of aggressive driving since the driver of test vehicle gets very little time to react. This is why an experienced driver with more than two decades of driving experience was chosen for this purpose. Antenna of data acquisition system was placed on fuel tank of the test vehicle and rest of the system was placed in the backpack carried by the driver. For safety reasons, number of trips recorded per day was restricted to two, since replicating vehicle movement while maintaining a constant distance can prove to be an exhausting process.

In case of 4W, onboard method was chosen for data acquisition and a ZEN Estilo VXi model manufactured by Suzuki was used as test vehicle. Specifications for the vehicle have been shown in Table 4.2. Peak hours have different traffic conditions as compared to off peak hours. In order to incorporate these impacts, data were collected in three different time slots: morning peak hours (09:00 a.m. – 11:00 a.m.), afternoon off peak hours (01.00 p.m. – 03.00 p.m.), and evening peak hours (06:00 p.m. – 08:00 p.m.).

Table 4.2: Test vehicle specifications



Engine	1061 cc, F10D Petrol
Number of Cylinder	4
Valves per Cylinder	4
Transmission Type	Manual
Gear Box	5 Speed
Drive Type	2WD
Fuel type	Petrol
Acceleration (0 – 100 kmph)	16.26 s
Seating Capacity	5
Length	3495 mm
Width	1495 mm
Height	1595 mm
Wheelbase	2360 mm
Vehicle Weight	855 kg

Raw data got stored initially in Secure Digital (SD) card of the data acquisition unit. At the end of each day, data stored in SD card was backed up into a computer to prevent data loss. In case of heavy discrepancy in collected data due to loss of signal or any technical error, respective data set was discarded and fresh data were recorded for the same. Still data obtained from logging unit contains minor discrepancies or impurities which need to be filtered or corrected (Duran and

Earleywine, 2012, Song and Lee, 2015). Some of these discrepancies observed in obtained data sets have been listed below:

- Presence of unusual data points due to temporary loss of signal.
- Unwanted data loss.
- Presence of unwanted transients.
- Presence of negative time stamp due to error in time stamp sequencing.
- Faulty zero readings and deviation from true zero readings.
- Unusually high readings.

Data filtration technique as described in a study of two wheeled and three wheeled vehicles by Majumdar (2022) was used for filtering raw data.

4.2.3 Data Processing:

The flowchart for data processing and DC generation has been shown in Figure 4.6. Post data filtration, parameters are generated based on which the DC is later evaluated. These parameter have been identified from studies conducted by Nesamani and Subramanian (2011), Kumar et al. (2012), Galgamuwa et al. (2015), Seedam et al., (2015), Arun et al., (2017), and Pathak et al., (2017).

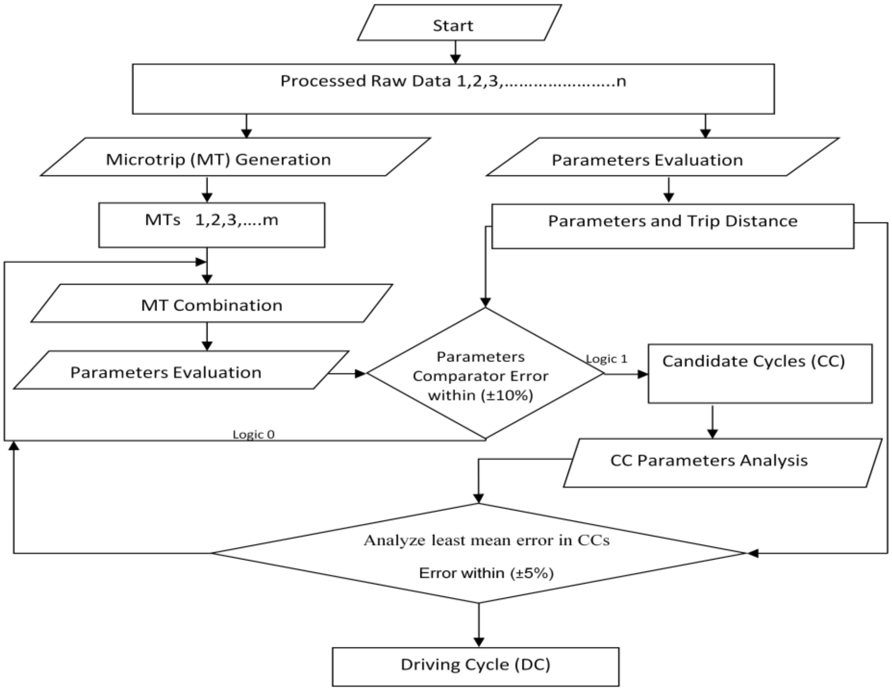


Figure 4.6: DC generation flowchart

15 parameters that were chosen for evaluation have been described below:

- **Number of stops per km (N_s):** Represents number of times the vehicle stopped while travelling a unit distance. Stoppage of vehicle could be due to congested roads, traffic signals or scheduled stops as in case of buses. Expressed in Nos./km.
- **Average moving speed ($V_{m_{avg}}$):** Represents average speed of the vehicle while it was moving. It does not take into account the time for which the vehicle halted. Expressed in km/h.

$$V_{m_{avg}} = \frac{Total\ distance\ travelled\ by\ the\ vehicle}{Total\ time\ for\ which\ the\ vehicle\ moved}\ \text{km/h}$$

- **Average speed (V_{avg}):** Represents average speed of the vehicle during the journey. Expressed in km/h.

$$V_{avg} = \frac{Total\ distance\ travelled\ by\ the\ vehicle\ (trip\ distance\ )}{Total\ time\ taken\ to\ travel\ the\ above\ mentioned\ distance\ (trip\ time\ )}\ \text{km/h}$$

- **Maximum Speed (V_{max}):** Represents maximum speed recorded in whole speed time data inventory. Expressed in km/h
- **Percentage idling time (T_i):** Represents time for which the vehicle remained stationary during its journey. Expressed as percentage of total trip time.

$$T_i = \frac{time\ spent\ by\ vehicle\ in\ idling\ mode\ or\ at\ zero\ velocity}{total\ trip\ time} \times 100\ \%$$

- **Percentage time in cruising mode (T_c):** Represents time for which the vehicle moved with speed more than 5 km/h while rate of acceleration or deceleration was less than 0.1 m/s^2. Expressed as percentage of total trip time.

$$T_c = \frac{time\ with\ speed > 5\ km/h\ and\ acceleratio\ n\ or\ deceleration\ < 0.1 m/s^2}{total\ trip\ time} \times 100\ \%$$

- **Percentage time in creeping mode (T_{cr}):** Represents time for which the vehicle moved with speed less than 5 km/h while rate of acceleration or deceleration was less than 0.1 m/s^2. Expressed as percentage of total trip time.

$$T_{cr} = \frac{time\ with\ speed < 5\ km/h\ and\ acceleration\ or\ deceleration\ < 0.1 m/s^2}{total\ trip\ time} \times 100\ \%$$

- **Percentage time in deceleration mode (T_d):** Represents time for which the vehicle moved with speed more than 5 km/h while rate of deceleration was greater than 0.1 m/s^2. Expressed as percentage of total trip time.

$$T_d = \frac{time\ \ with\ speed > 5\ km/h\ and\ \ deceleration\ \ > 0.1 m/s^2}{total\ \ trip\ \ time} \times 100\ \%$$

- **Percentage time in acceleration mode (T_a):** Represents time for which the vehicle moved with speed more than 5 km/h while rate of acceleration was greater than 0.1 m/s^2. Expressed as percentage of total trip time.

$$T_d = \frac{time\ \ with\ speed > 5\ km/h\ and\ \ acceleration\ \ > 0.1 m/s^2}{total\ \ trip\ \ time} \times 100\ \%$$

- **Net positive kinetic energy (KE_{n+}):** Represents energy required for acceleration by the vehicle. Expressed in m/s^2.

$$KE_{n+} = \frac{\sum V_i^2 - V_{i-1}^2}{total\ \ distance}\ \text{m/s}^2$$

- **Maximum positive acceleration (A_{max}):** Represents maximum acceleration recorded in survey. Expressed in m/s^2.
- **Maximum deceleration (D_{max}):** Represents maximum deceleration recorded in survey. Expressed in m/s^2.
- **Average positive acceleration (A_{avg}):** Represents mean of accelerations recorded in a trip. Expressed in m/s^2.
- **Average deceleration (D_{avg}):** Represents mean of decelerations recorded in a trip. Expressed in m/s^2.
- **Root Mean Square (RMS) acceleration (A_{rms}):** Represents root mean squared value of all acceleration and deceleration events obtained from the survey. Expressed in m/s^2.

$$A_{rms} = \sqrt{\frac{\sum_i \boldsymbol{a_i^2}}{\boldsymbol{N}}}\ \text{m/s}^2$$

  where, a_i denotes acceleration and deceleration value corresponding to an event, *i* denotes that particular event, and *N* denotes total number of events.

These parameters were obtained by analyzing data in MATLAB software. Microtrip generation was next step in the process.

4.2.4 Microtrip Generation, Combination and DC:

There are various techniques of generating a DC. Most popular among them are Microtrip (MT) method, Markov chain Monte Carlo (MC-MC) method and fuel based (FB) method (Huertas et al., 2019, Mayakuntla and Verma, 2018, Chandrashekar et al., 2021). Huertas et al. (2019)

showed that MT method represented real world data better as compared to MC-MC method. According to Mayakuntla and Verma (2018), real world urban driving characteristics for regional DC can be accurately represented by MT method. Based on this, MT method was chosen for this study. MT can be defined as an event of movement with positive acceleration which starts and ends at zero velocity. MTs were generated using MATLAB software. After the MTs have been generated, valid MTs were combined to form potential candidate cycle (CC) which can represent the travel pattern of a vehicle. Two methods are generally used for combining MT segments: random selection method and *k*-means clustering technique. Chandrashekar et al. (2021) studied both these methods and inferred that although both the techniques yielded similar results, the later one gave a slightly better representation of real world scenario. Based on this inference, *k*-means clustering technique was used for MT combination in this study.

Once MTs were combined, parameters of these combinations were evaluated with parameters initially obtained from raw data. If the error for individual parameter was within a tolerance limit of ±10%, it was considered to be a candidate cycle. If error exceeded tolerance limit, the set was discarded and sent for recombination. Parameters of the CC were further analyzed for cumulative error (E_{cum}) and mean error (E_{mean}) which were calculated as shown in equations 4.1 and 4.2. If the maximum mean error was within tolerance limit of ±5%, it is qualified to be a DC. Final DC is chosen based on least error, or least distance travelled and least time taken in case errors are comparably close.

$$E_{cum} = \sum_i \frac{\left|P_{raw\ i} - P_{mt\ i}\right|}{P_{raw\ i}} \times 100 \tag{4.1}$$

$$E_{mean} = \frac{E_{cum}}{N} \tag{4.2}$$

where, $P_{raw\ i}$ = i^{th} parameter of raw data

$P_{mt\ i}$ = i^{th} parameter of MT data

N = number of parameters

4.3 Results and Discussions:

Parameters generated from filtered raw data for ICE bus, eBus and 4W have been shown in Table 4.3. These values forms the basis based on which the DCs are finally evaluated.

Table 4.3: Parameters derived from raw data

Parameters	**ICE Bus**	**eBus**	**4W**
Number of Stops (Nos./km)	1.65	1.16	0.81
Average moving speed (km/h)	17.78	23.51	25.6
Average speed (km/h)	12.68	17.87	19.23
Maximum speed (km/h)	63.42	69.47	84.37
Percentage idling time (%)	28.63	24.9	26.57
Percentage time in cruising mode (%)	10.51	10.21	13.25
Percentage time in creeping mode (%)	6.57	4.96	4.09
Percentage time in deceleration mode (%)	22.69	24.92	26.96
Percentage time in acceleration mode (%)	26.31	30.08	29.05
Net Positive Kinetic Energy (m/s^2)	0.39	0.42	0.36
Maximum acceleration (m/s^2)	4.45	3.51	3.98
Maximum deceleration (m/s^2)	3.43	3.51	4.59
Average acceleration (m/s^2)	0.44	0.46	0.41
Average deceleration (m/s^2)	0.48	0.53	0.43
RMS acceleration (m/s^2)	0.63	0.66	0.59

Random MTs that were generated for buses and 4W have been shown in Figure 4.7-4.9. It can be easily observed that each MT graph starts from a ‘0’ value and ends in a ‘0’ value depicting feature of MT as already mentioned earlier. At end of some MT curves, there is a stretch of ‘0’ values which represents idling condition of the vehicle.

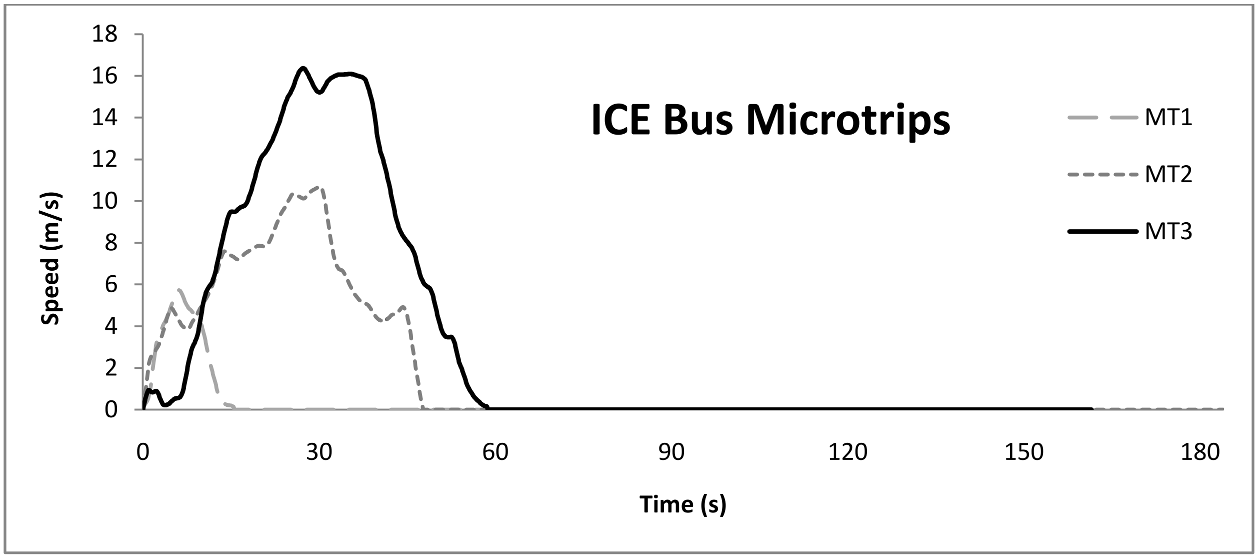


Figure 4.7: Random MTs generated for ICE Bus

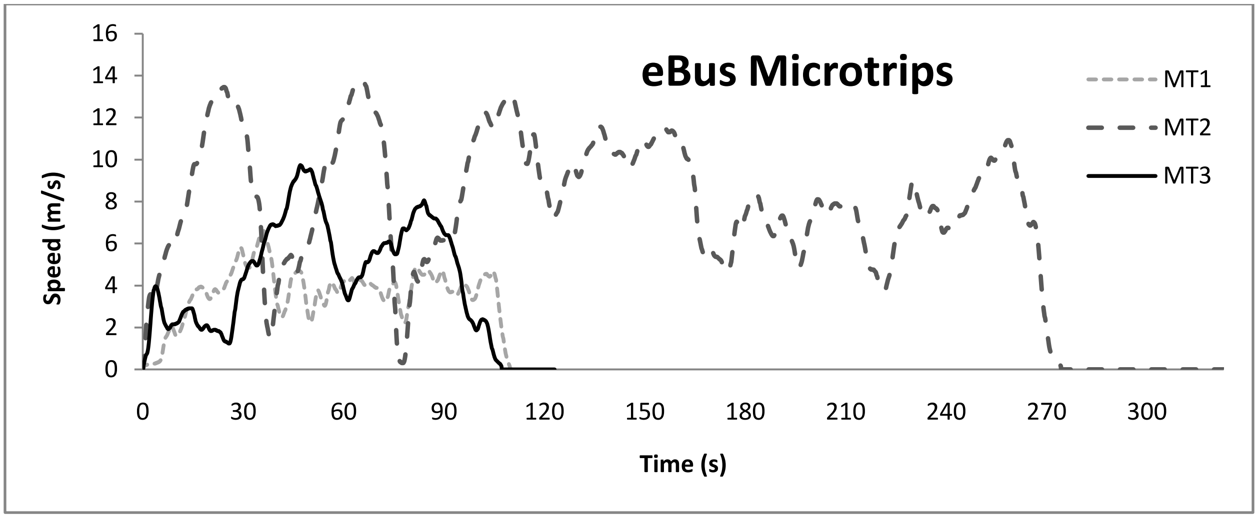


Figure 4.8: Random MTs generated for eBus

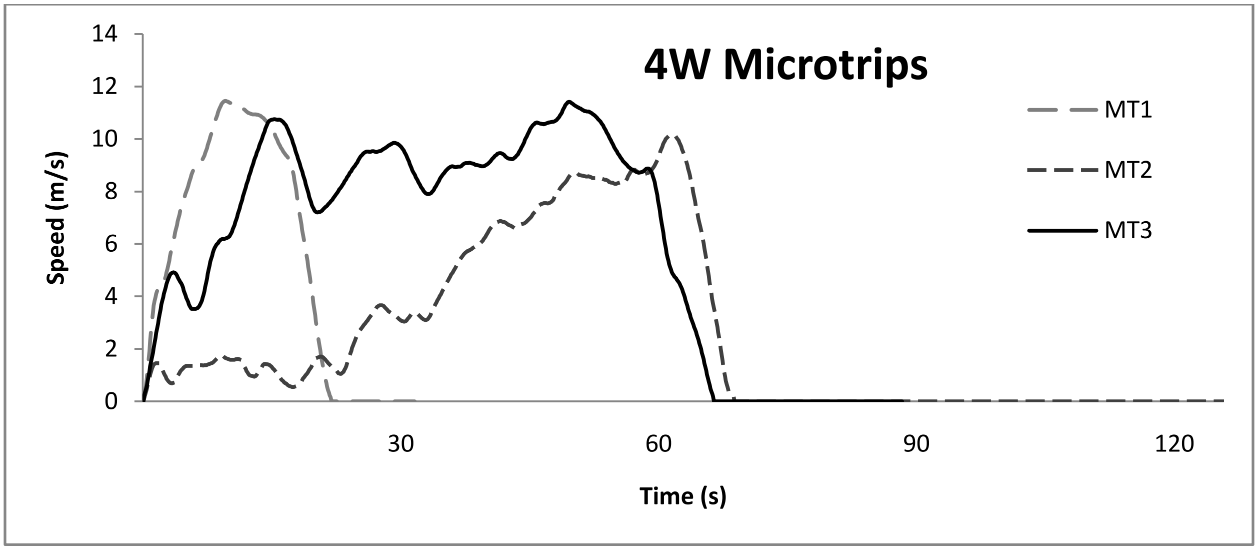


Figure 4.9: Random MTs generated for 4W

Multiple such MTs get combined using the *k*-means clustering technique. Based on V_{avg} and T_i, each MT was plotted in a two dimensional space and the cluster was obtained. Clusters generated for ICE Bus, eBus and 4W has been shown in Figure 4.10-4.12 respectively. It can be observed that MTs were clustered into 3 different groups where each group represents a particular traffic condition. In case of Kolkata, these traffic conditions have been considered as follows:

1. *Congested traffic condition*: characterized by very low driving speed, frequent halts and high idling time, represented by cluster 1.

2. *Urban traffic condition*: characterized by moderately low driving speed and idling time, represented by cluster 2.
3. *Extra urban traffic condition*: characterized by comparatively free traffic flow with moderately high driving speed and low idling time, represented by cluster 3.

It can be observed that in congested traffic condition the idling time for ICE bus, eBus and 4W varied approximately within the range of 52% – 93 %, 49% – 92%, and 57% – 96% respectively. In case of urban traffic condition, idling time for the same varied within approximate range of 25% – 52%, 20% – 49%, and 26% – 57% respectively. For extra urban traffic conditions, the range varied approximately between 0% to 25%, 20% and 26% respectively. The figures also show that major portions of cluster 2 and 3 have overlapping values for average vehicle speed for all three types of vehicles. This can be attributed to the traffic condition in Kolkata city which is often characterized by pockets of congested zones followed by stretches of uncongested free flowing roads. Another factor contributing to this is the maximum permissible speed of vehicles plying the streets. For urban routes, the maximum speed limit for all vehicles is 40 km/h.

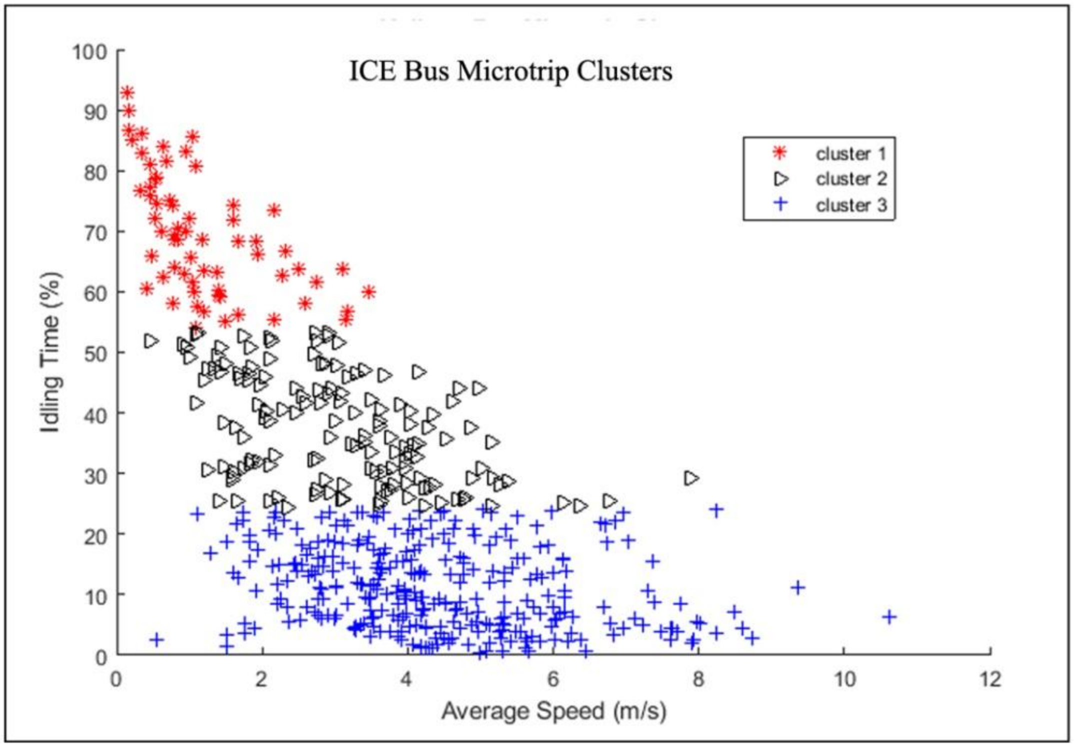


Figure 4.10: Cluster plot for ICE Bus

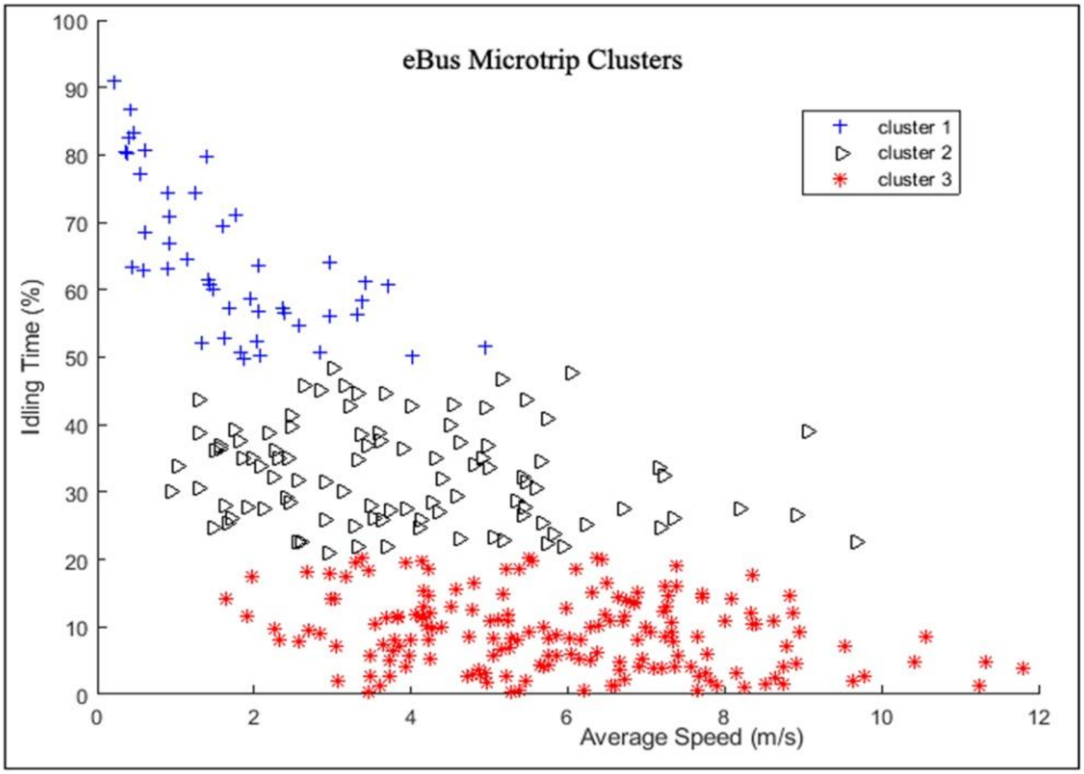


Figure 4.11: Cluster plot for eBus

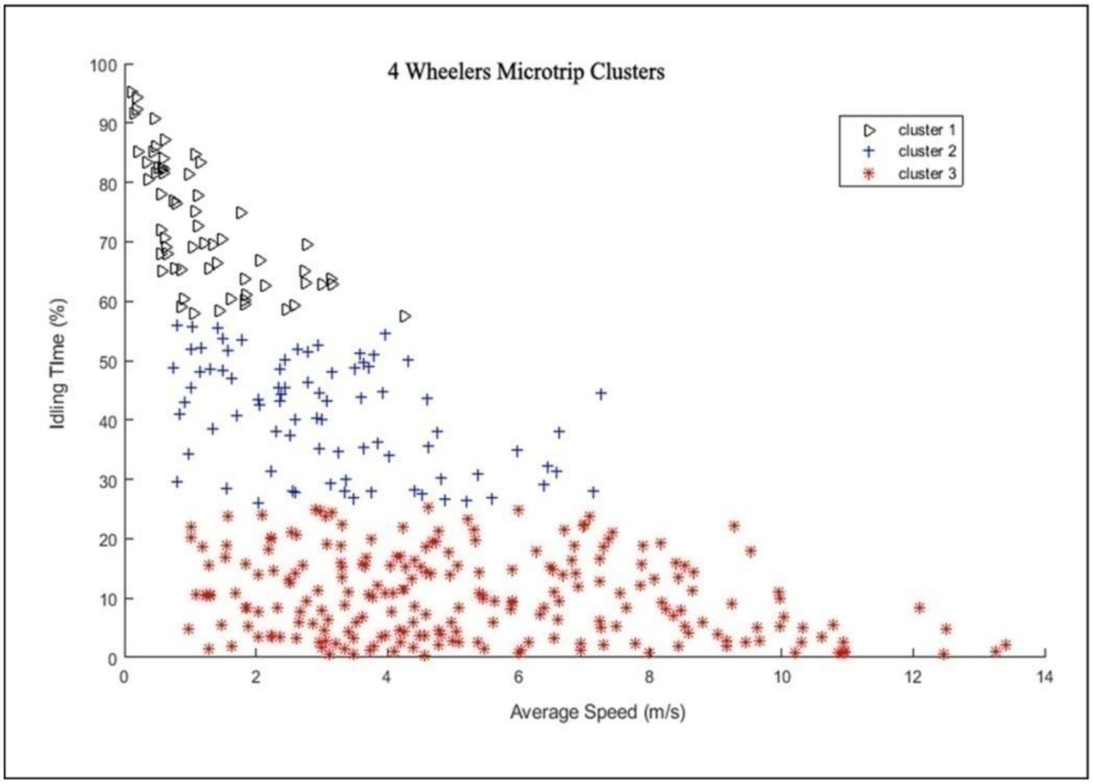


Figure 4.12: Cluster plot for 4W

However for arterial or extra urban routes, maximum speed limit for bus and 4W is 50 km/h and 60 km/h respectively. The impacts of capped speed limits are clearly visible in the clusters. Still there are occasions when drivers do not obey speed limits and drive their vehicles at excessive speeds whenever the road permits. Maximum speed recorded in this study for ICE bus, eBus and 4Wwas 63.42 km/h, 69.47 km/h and 84.37 km/h respectively. This explains the extremities in values of average speed seen in cluster plots.

It has already been discussed earlier that after formation of clusters and MT combination, CC were generated. Sample CC has been shown in Figures 4.13 – 4.15. After calculation of cumulative error, mean error and evaluation of least mean error, DC was obtained for the vehicles. Parameters obtained from DC have been compared with parameters obtained from raw data and shown in Table 4.4. Clearly it can be observed that the parameters fulfill individual error criteria of ± 10% and mean error criteria of ± 5% (Maurya and Bokare, 2012).

Speed Acceleration Probability Distribution (SAPD) analysis was done for generated DC using MATLAB software. SAPD distributions obtained for ICE Bus, eBus and 4W have been shown in Figures 4.16 – 4.18.

In case of ICE Bus, zone of activity varies within speed range of 10km/h and 35 km/h and acceleration range of ±1 m/s^2. For eBus, speed range varies between 10 km/h and 45 km/h whereas acceleration varies within range of ±1 m/s^2. Similarly 4W showed maximum speed variation within range of 6 km/h and 46 km/h while certain fluctuations were observed above 60 km/h range. Acceleration range for the same varied within ±1 m/s^2 range. Results of this analysis showed that data obtained from DC were in parity with raw data and that the DCs were able to represent the driving conditions of this location.

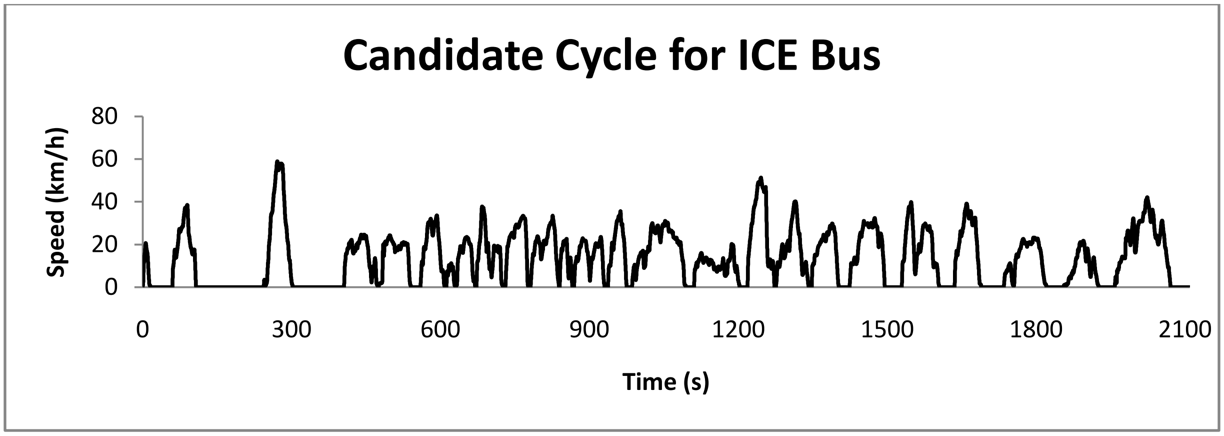


Figure 4.13: Sample Candidate Cycle for ICE Bus

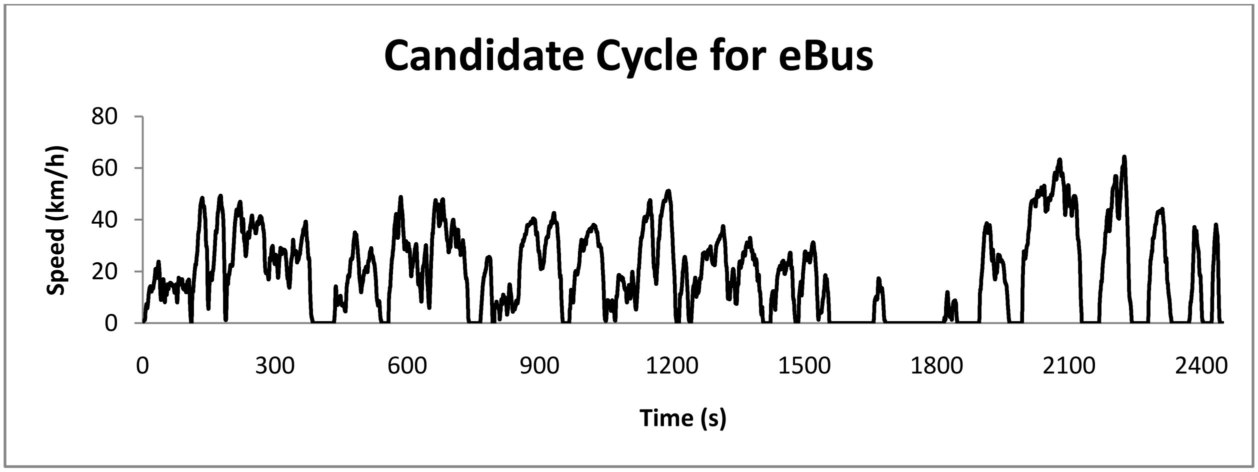


Figure 4.14: Sample Candidate Cycle for eBus

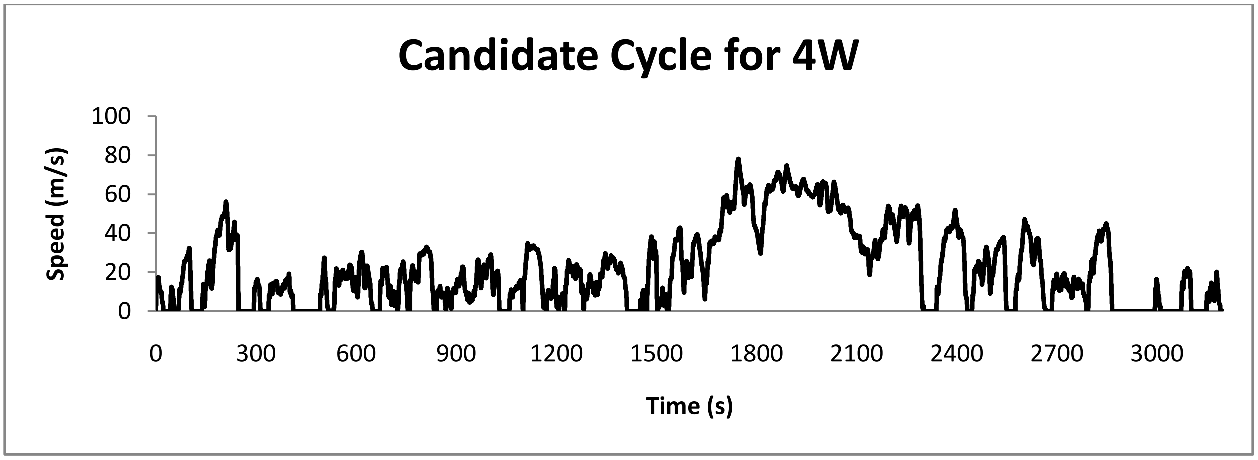


Figure 4.15: Sample Candidate Cycle for 4W

Table 4.4: Raw data and DC parameter comparison

Parameters	Symbols	Units	ICE Bus			eBus			4W		
			Raw Data Parameter Value	DC Parameter Value	Error (%)	Raw Data Parameter Value	DC Parameter Value	Error (%)	Raw Data Parameter Value	DC Parameter Value	Error (%)
Number of Stops	N_s	Nos./km	1.65	1.56	5.45	1.16	1.06	8.62	0.81	0.73	9.88
Average Moving Speed	V_{mavg}	km/h	17.78	18.61	4.67	23.51	23.87	1.53	25.6	27.23	6.37
Average Speed	V_{avg}	km/h	12.68	12.79	0.87	17.87	17.87	0.00	19.23	19.4	0.88
Maximum Speed	V_{max}	km/h	63.42	63.42	0.00	69.47	63.26	8.94	84.37	78.16	7.36
Percentage Idling Time	T_i	%	28.63	31.29	9.29	24.9	25.16	1.04	26.57	28.77	8.28
Percentage Time in Cruising mode	T_c	%	10.51	10.54	0.29	10.21	10.32	1.08	13.25	12.78	3.55
Percentage Time in Creeping Mode	T_{cr}	%	6.57	6.7	1.98	4.96	4.95	0.20	4.09	4.23	3.42
Percentage Time in Deceleration Mode	T_d	%	22.69	23.64	4.19	24.92	27.11	8.79	26.96	26.94	0.07
Percentage Time in Acceleration Mode	T_a	%	26.31	27.84	5.82	30.08	32.47	7.95	29.05	27.28	6.09
Net Positive Kinetic Energy	KE_{n+}	m/s^2	0.39	0.4	2.56	0.42	0.43	2.38	0.36	0.35	2.78
Max Positive Acceleration	A_{max}	m/s^2	4.45	4.4	1.12	3.51	3.51	0.00	3.98	3.8	4.52
Maximum Deceleration	D_{max}	m/s^2	3.43	3.36	2.04	3.51	3.51	0.00	4.59	4.59	0.00
Average Positive Acceleration	A_{avg}	m/s^2	0.44	0.44	0.00	0.46	0.46	0.00	0.41	0.42	2.44
Average Deceleration	D_{avg}	m/s^2	0.48	0.48	0.00	0.53	0.53	0.00	0.43	0.42	2.33
RMS Acceleration	A_{rms}	m/s^2	0.63	0.64	1.59	0.66	0.66	0.00	0.59	0.6	1.69
Mean Error	E_{mean}	%			2.66			2.70			3.98

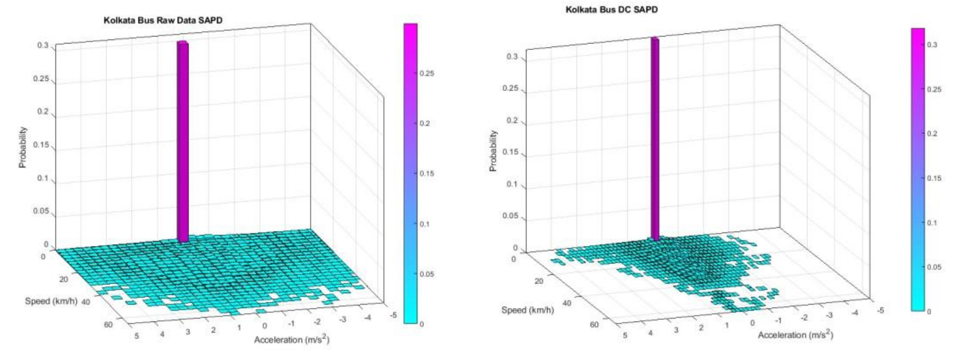


Figure 4.16: SAPD distribution for ICE Bus

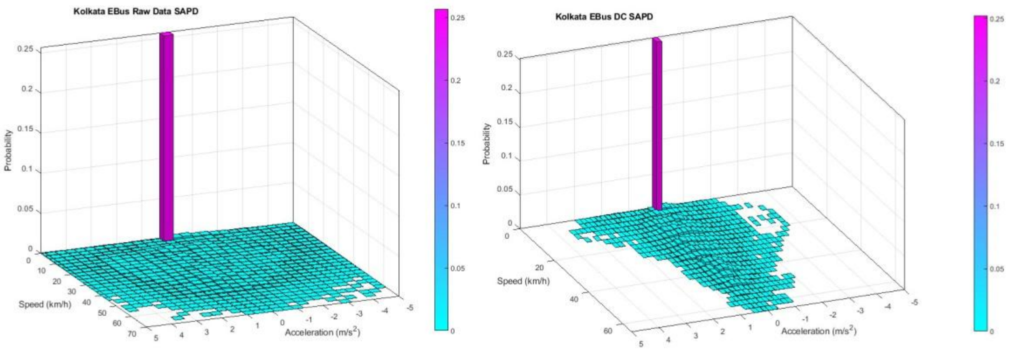


Figure 4.17: SAPD distribution for eBus

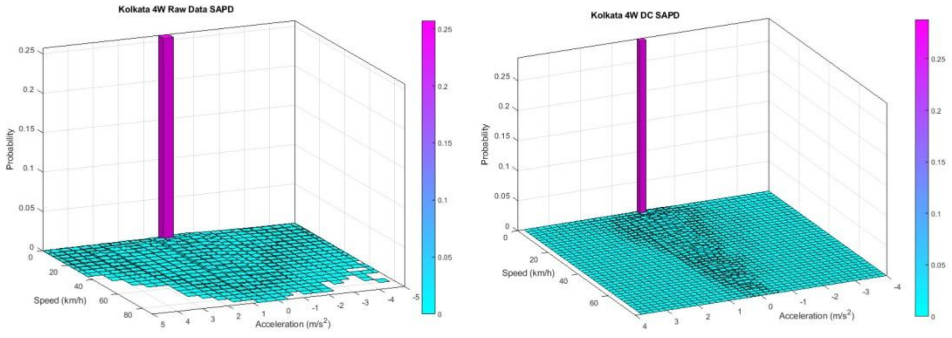


Figure 4.18: SAPD distribution for 4W

Figures 4.19 – 4.21 shows the final DC for ICE Bus, eBus and 4W in Kolkata and are referred to as KBDC, KEBDC and K4WDC respectively.

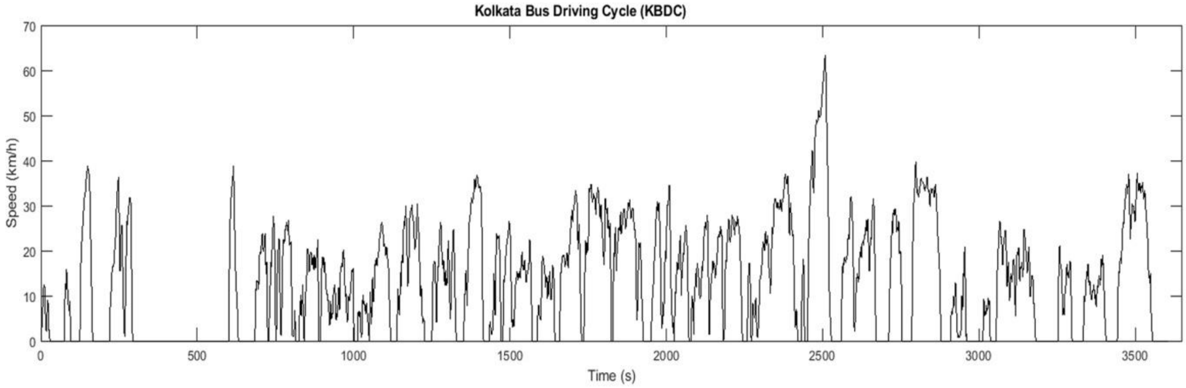


Figure 4.19: Kolkata ICE Bus Driving Cycle (KBDC)

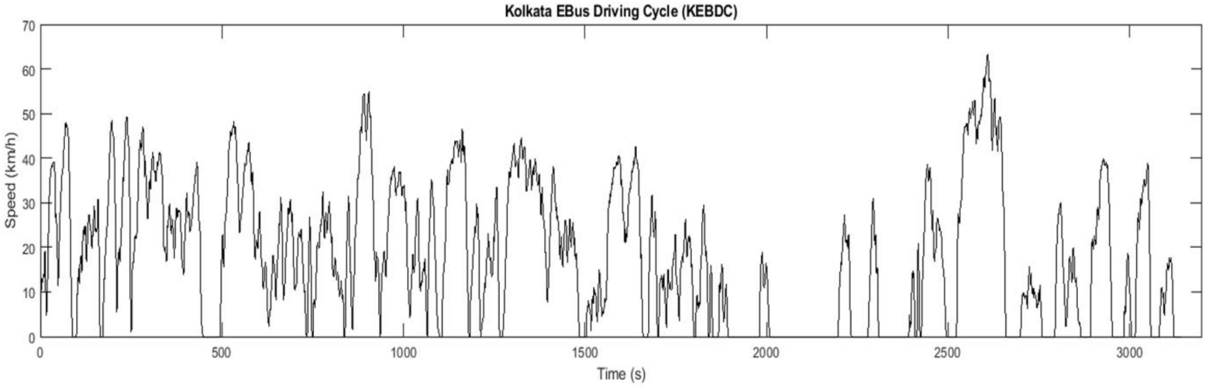


Figure 4.20: Kolkata eBus Driving Cycle (KEBDC)

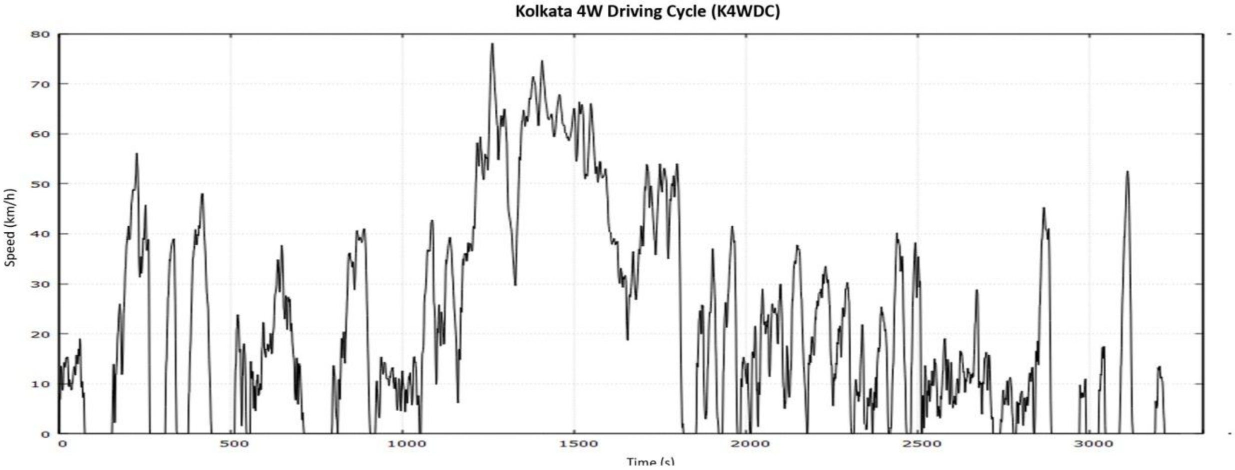


Figure 4.21: Kolkata 4W Driving Cycle (K4WDC)

Parameters obtained from KBDC, KEBDC and K4WDC has been compared with available Indian and international DCs as shown in Tables 4.5 and 4.6.

Table 4.5: Comparison of bus Driving Cycle

Driving Cycles	Source	Number of Stops (Nos./km)	Average moving speed (km/h)	Average speed (km/h)	Maximum speed (km/h)	Percentage idling time	Percentage time in cruising mode	Percentage time in creeping mode	Percentage time in deceleration mode	Percentage time in acceleration mode	Net Positive Kinetic Energy (m/s^2)	Maximum acceleration (m/s^2)	Maximum deceleration (m/s^2)	Average acceleration (m/s^2)	Average deceleration (m/s^2)	RMS acceleration (m/s^2)
ICE Bus	Present Study	1.56	18.61	12.79	63.42	31.29	10.54	6.70	23.64	27.84	0.40	4.40	-3.36	0.44	0.48	0.64
eBus	Present Study	1.06	23.87	17.87	63.26	25.16	10.32	4.95	27.11	32.47	0.43	3.51	-3.51	0.46	0.53	0.66
Delhi Bus Driving Cycle	Kumar et al. (2013)		-	27.05	-	14.03	9.66	-	36.62	39.69	-	-	-	-	-	-
Delhi Bus Driving Cycle (DBDC)	Badusha and Ghosh (2018)	2.00	22.65	17.72	-	21.96	8.24	-	32.50	37.30	-	-	-	0.38	0.44	-
Pune Driving Cycle	Kamble et al. (2009)		-	19.55	-	18.09	56.25	-	11.48	14.18	-	-	-	3.72	4.57	-
Maharashtra Highway Morning Peak	Maurya and Bokare (2012)		39.74	37.69	-	5.18	46.62	-	21.54	25.98	0.45	-	-	0.28	0.37	0.34
Maharashtra Highway Off Peak	Maurya and Bokare (2012)		47.12	44.10	-	4.27	53.53	-	15.53	26.98	0.63	-	-	0.33	0.31	0.45
Maharashtra Highway Evening Peak	Maurya and Bokare (2012)		34.38	31.00	-	9.62	36.46	-	14.85	38.21	0.52	-	-	0.28	0.60	0.33
Chennai Bus Driving Cycle	Nesamani and Subramanian (2011)		-	14.00	-	32.20	3.50	4.90	29.60	29.80	-	-	-	0.65	0.71	-
Indian Driving Cycle (IDC)	Badusha and Ghosh (2018)		26.22	21.89	-	16.52	10.43	-	33.91	39.13	-	-	-	0.47	0.54	-
Islamabad Driving Cycle	Bhatti et al. (2021)		-	29.53	82.74	15.33	21.33	-	25.25	38.08	-	2.41	-2.89	0.39	0.51	0.54
Shanghai Intra City Hybrid Electric Bus (Route 993 HEB)	Shen et al. 2018		-	23.00	69.20	34.00	5.00	-	28.00	33.00	-	2.91	-2.91	0.71	0.83	-
Hong Kong Inter District	Tong and Ng (2021)		51.48	45.20	-	12.19	7.43	0.72	39.53	40.12	0.51	-	-	0.81	0.82	0.95
Hong Kong Within District	Tong and Ng (2021)		23.10	14.45	-	37.44	3.73	1.38	28.34	29.10	0.64	-	-	0.88	0.90	1.03
Hong Kong Peak Hours	Tong and Ng (2021)		22.53	14.91	-	33.91	4.06	1.42	30.17	30.54	0.63	-	-	0.91	0.91	1.05
Hong Kong Off Peak Hours (Day)	Tong and Ng (2021)		37.26	26.40	-	29.44	5.11	1.14	32.16	32.45	0.50	-	-	0.81	0.82	0.96
Hong Kong Off Peak Hours (Night)	Tong and Ng (2021)		39.58	31.32	-	20.87	5.18	0.74	35.71	37.50	0.56	-	-	0.86	0.90	1.01
Hanoi Bus Driving Cycle	Nguyen et al. (2018)		-	16.80	-	7.60	14.10	-	32.70	34.20	-	-	-	0.50	0.52	-
Fuzhou Bus Driving Cycle	Peng et al. (2019a)		-	13.80	-	34.40	15.50	-	23.10	27.00	-	-	-	0.74	-	-
Mexico City Urban 1 Driving Cycle	Quirama et al. (2020)		-	7.30	-	15.50	22.70	-	29.30	32.90	-	-	-	0.50	0.50	-
Mexico City Urban 2 Driving Cycle	Quirama et al. (2020)		-	10.00	-	13.60	25.90	-	29.10	33.80	-	-	-	0.40	0.50	-

Table 4.6: Comparison of 4W Driving Cycle

Driving Cycles	Source	Number of Stops (Nos./km)	Average moving speed (km/h)	Average speed (km/h)	Maximum speed (km/h)	Percentage idling time	Percentage time in cruising mode	Percentage time in creeping mode	Percentage time in deceleration mode	Percentage time in acceleration mode	Net Positive Kinetic Energy (m/s²)	Maximum acceleration (m/s²)	Maximum deceleration (m/s²)	Average acceleration (m/s²)	Average deceleration (m/s²)	RMS acceleration (m/s²)
4W	Present Study	0.73	27.23	19.40	78.16	28.77	12.78	4.23	26.94	27.28	0.35	3.80	-4.59	0.42	0.42	0.60
Pune Driving Cycle	Kamble et al. (2009)	-	-	19.55	-	18.09	56.25	-	11.48	14.18	-	-	-	3.72	4.57	-
Ludhiana City Driving Cycle	Yugendar et al. (2020)	-	-	24.83	-	5.40	2.39	-	41.17	51.00	-	-	-	-	-	-
Passenger Cars	Adak et al. (2016)	-	17.55	17.42	39.1	0.74	12.28	-	41.39	45.62	-	-	-	0.15	0.13	0.41
IDC for Motor Vehicles	Adak et al. (2016)	-	26.08	21.92	42	15.93	12.18	-	33.63	38.31	-	-	-	0.74	0.89	2.06
MIDC for Passenger Cars	Adak et al. (2016)	-	37.54	26.88	90	28.4	35.17	-	15.78	20.71	-	-	-	0.58	0.89	2.75

Analysis of bus DC revealed that average speed for KEBDC was 39.72% higher, average acceleration was 4.55% higher, average deceleration was 10.42% higher and percentage idling time was 19.59% lower as compared to KBDC (Table 4.7). On comparison with DC developed by Kumar et al. (2013) it was observed that average speed for KBDC and KEBDC was 52.72% and 33.94% lesser whereas percentage idling time was 123.02% and 79.33% more respectively. When compared with DBDC developed by Badusha and Ghosh (2018), it was observed that although average speed for KBDC was 27.82% less, KEBDC reported a closer resemblance with a mere 0.85% deviation. Percentage idling time was 42.49% more for KBDC and 14.57% more for KEBDC. Average speed for Pune DC developed by Kamble et al. (2009) was 34.58% more than KBDC and 8.59% more than KEBDC whereas percentage idling time was 72.97% and 39.08% less respectively. Chennai bus DC reported by Nesamani and Subramanian (2011) deviated by 8.64% and 27.64% for average speed and 2.83% and 21.86% for percentage idling time as compared to KBDC and KEBDC respectively.

When DCs for 4W were considered, average speed for Ludhiana DC developed by Yugendar et al. (2020) was 21.88% more and percentage idling time was 432.39% less as compared to K4WDC. In case of DC for passenger cars developed by Adak et al. (2016), it was observed that average speed for K4WDC was 11.35% more. For MIDC for passenger cars (Adak et al., 2016) average speed was 27.84% more and percentage idling time was 1.3% less as compared to K4WDC. The values obtained from KBDC, KEBDC and K4WDC were within the range of DCs that are available in India. The values for average speed, average acceleration, average deceleration and percentage idling time along with range among DCs used in India have been shown in Table 4.7 and 4.8.

Table 4.7: Parameter comparison for bus

Parameters	**ICE Bus**	**eBus**	**Range among available IDCs**
Average Speed (km/h)	12.79	17.87	14.00 - 44.10
Average Acceleration (m/s^2)	0.44	0.46	0.28 - 3.72
Average Deceleration (m/s^2)	0.48	0.53	0.31 - 4.57
Percentage Idling Time (%)	31.29	25.16	4.27 - 32.20

Table 4.8: Parameter comparison for 4W

Parameters	**4W**	**Range among available IDCs**
Average Speed (km/h)	19.40	17.42 - 26.88
Average Acceleration (m/s^2)	0.42	0.15 - 3.72
Average Deceleration (m/s^2)	0.42	0.13 - 4.57
Percentage Idling Time (%)	28.77	0.74 - 28.40

Figures 4.22-4.24 shows the percentage of time spent by vehicles in different driving modes. It may be observed that an ICE bus spends maximum time in idling mode (31.29%) and minimum time in creeping mode (6.70%) while over 50% of time is spent in accelerating or decelerating mode. An eBus on the other hand spends maximum time in acceleration mode (32.47%) while minimum time on creeping mode (4.95%). Both ICE bus and eBus spends just over 10% of time in cruising mode. 4W on the other hand spends a little more time (12.78%) in cruising mode. Like ICE bus, 4W spend over 50% of time in acceleration or deceleration mode and maximum time in idling mode (28.77%). Data obtained from DC reveals overall slow moving nature of traffic with frequent accelerations and decelerations and limited cruising opportunity. Further

attempt was made to utilize information obtained from DC to estimate fuel consumption for vehicles. This has been discussed in the following sections.

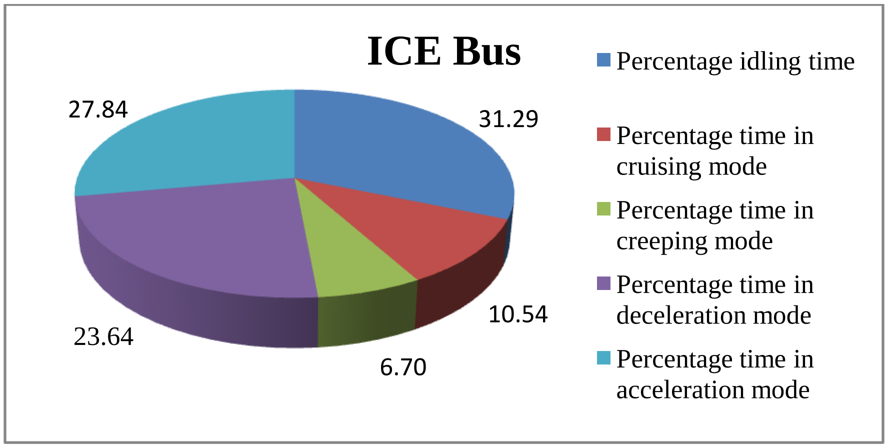


Figure 4.22: Time spent in different driving modes for ICE Bus

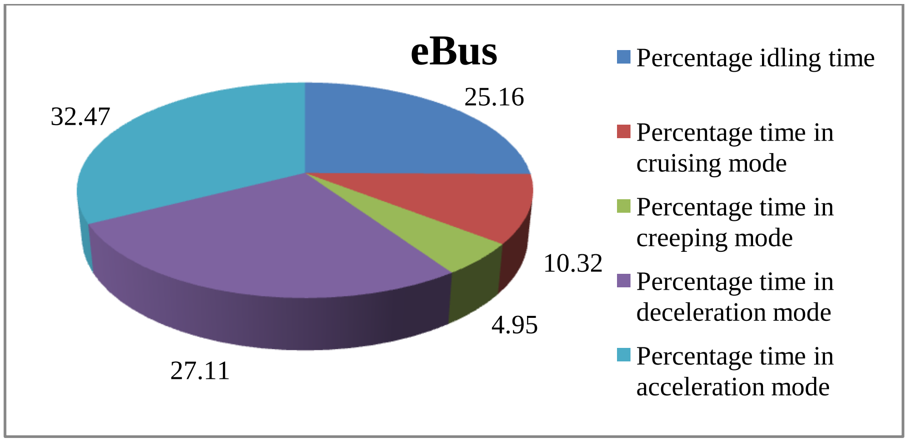


Figure 4.23: Time spent in different driving modes for eBus

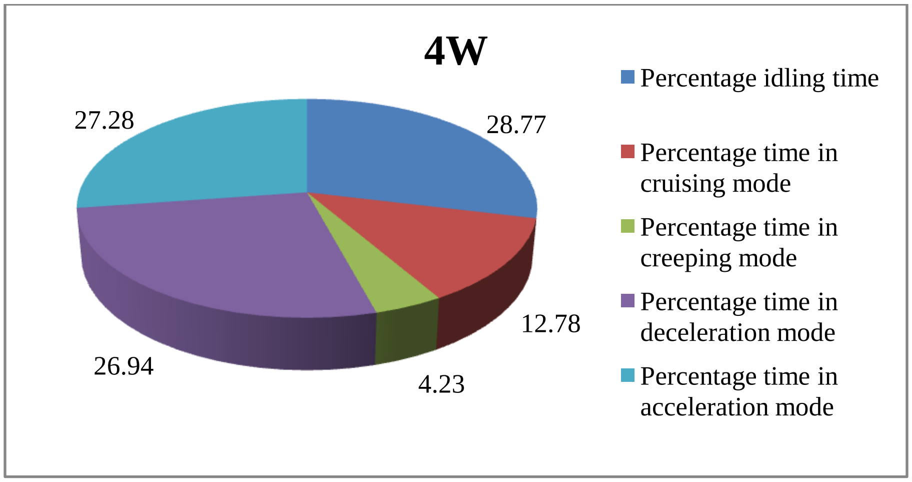


Figure 4.24: Time spent in different driving modes for 4W

4.4 Estimation of Fuel Consumption from DC data:

It has already been discussed earlier that fuel consumption of a vehicle gets influenced by various factors. The effects of most of these factors get incorporated in DC. Therefore, if fuel consumption can be estimated utilizing information obtained from DC, it might be helpful in analyzing the consumption scenario.

Speed of a vehicle influences fuel consumption. Hence fuel consumption estimation was divided into two segments: fuel consumption during motion and fuel consumption during idling. Fuel consumption during motion was calculated using average moving speed data whereas fuel consumption during idling was calculated using idling time and distance data obtained from KBDC and K4WDC. Consumption in each case was calculated individually and summed to obtain final consumption. In this study fuel consumption was calculated for diesel fueled buses and 4Ws that represented the majority of public transit vehicles in the road transport sector. The steps involved in estimating the same has been discussed in following sections.

4.4.1 Formula for calculating fuel consumption during motion:

Equations for estimation of fuel consumption for different types of vehicles are referred from Manual for Economic Evaluation of Highway Projects in India, 2009 (Indian Road Congress, 2009). Equations 4.3 and 4.4 shown below have been utilized in this study for estimating consumption of buses and cars. Equation for 3W was not available and hence estimating the same was kept outside the scope of this study.

$$FC_{m_{bus}} = 32.97 + \frac{3904.64}{V} + (0.0207 \times V^2) + (0.0012 \times RG) + (3.3281 \times RS) - (1.7769 \times FL) \tag{4.3}$$

$$FC_{m_{car}} = 21.85 + \frac{504.15}{V} + (0.004957 \times V^2) + (0.000652 \times RG) + (1.0684 \times RS) - (0.3684 \times FL) \tag{4.4}$$

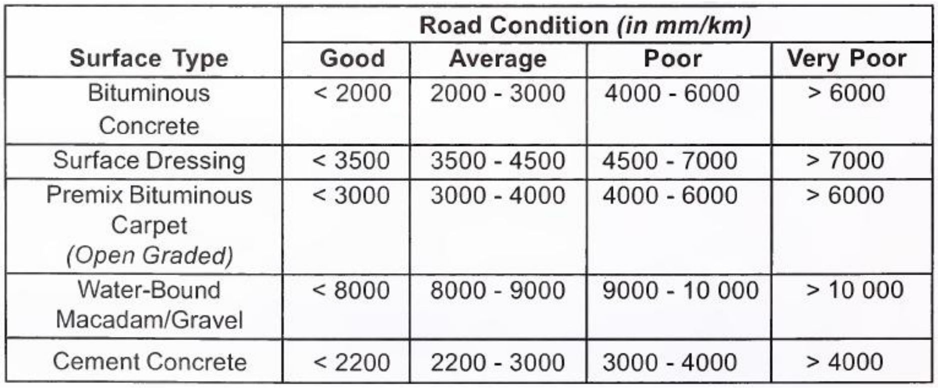
where, $FC_{m_{bus}}$: Fuel consumption at motion for bus (l/km)
$FC_{m_{car}}$: Fuel consumption at motion for car (l/km)
V : Average speed of vehicle (km/h)
RG : Roughness of road (mm/km)
RS : Rise (m/km)
FL : Fall (m/km)

RG, *RS* and *FL* have been discussed in the following sections.

4.4.2 Roughness of Road:

Roughness of road is a crucial factor that can impact speed of vehicles plying the streets and thus fuel consumption (Abulizi et al., 2016). It can be defined as cumulative measure of irregularities on road surface per unit road length. It is measured by British Towed Fifth Wheel Bump Integrator (BI). Recommended roughness values for Indian road have been shown in Table 4.9 (Indian Road Congress, 2009).

Table 4.9: Recommended roughness values for Indian roads



Surface Type	**Road Condition *(in mm/km)***			
	Good	**Average**	**Poor**	**Very Poor**
Bituminous Concrete	< 2000	2000 - 3000	4000 - 6000	> 6000
Surface Dressing	< 3500	3500 - 4500	4500 - 7000	> 7000
Premix Bituminous Carpet *(Open Graded)*	< 3000	3000 - 4000	4000 - 6000	> 6000
Water-Bound Macadam/Gravel	< 8000	8000 - 9000	9000 - 10 000	> 10 000
Cement Concrete	< 2200	2200 - 3000	3000 - 4000	> 4000

Considering surface type of roads surveyed similar to surface dressing and conditions of roads throughout the year varying within range of average to poor, the value for roughness of roads have been considered to be 4500 mm/km for this study.

4.4.3 Rise and Fall:

Elevation of road has its own impact on fuel consumption. While climbing uphill, a vehicle consumes more power and hence fuel consumption should be more. Similarly, while going downhill, less power is consumed and hence ideally fuel consumption should be less. Although Kolkata can be considered to be a plain land, the presence of flyovers and bridges in the routes surveyed makes it necessary to consider the vertical profile of the road. The process of calculation of rise and fall was referred from Manual on Economic Evaluation of Highway Projects in India, (Indian Road Congress, 2009). The following portion explains how the rise and fall was calculated.

Let AB represent a stretch of road having length *d* km (Figure 4.25). There are 3 points of elevation represented by Bridge 1-3. Considering direction of movement, rises encountered by the vehicle are h_1, h_3 and h_5 mm respectively. Similarly falls dealt with by the vehicle are h_2, h_4 and h_6 mm respectively. Therefore RS and FL for this road can be calculated as shown in equations 4.5 and 4.6.

Rise in road section AB,

$$RS = \frac{h_1+h_3+h_5}{d} \tag{4.5}$$

Fall in road section AB,

$$FL = \frac{h_2+h_4+h_6}{d} \tag{4.6}$$

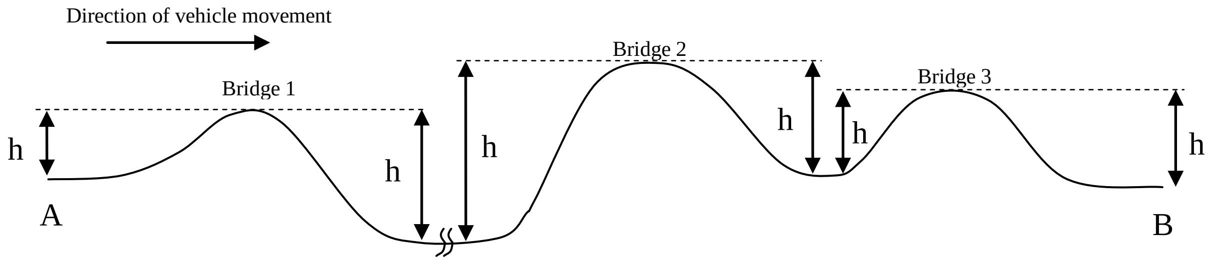


Figure 4.25: Rise and Fall in a road section

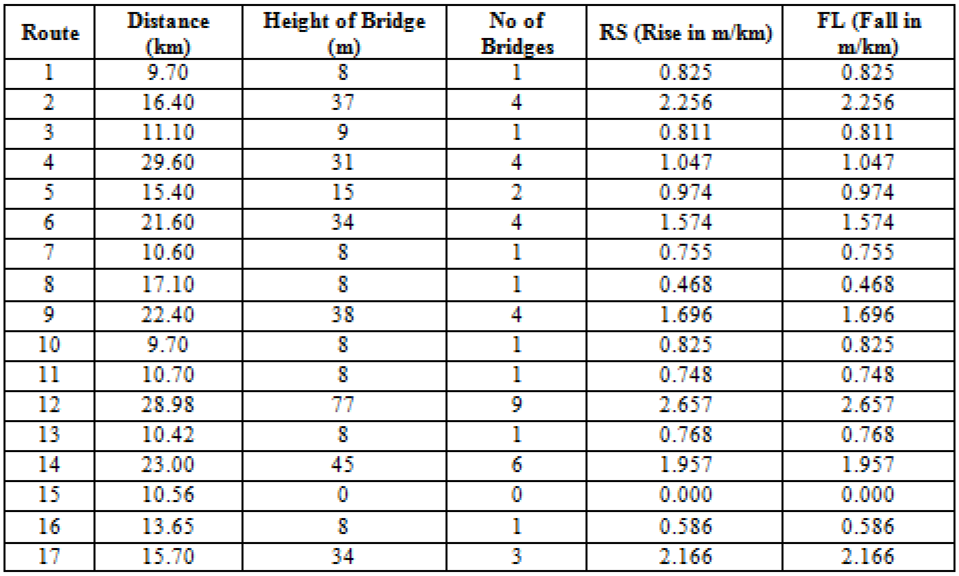
For this study, elevation of roads at the starting and after the end of a bridge or flyover was assumed to be '0' m. Bridges encountered in the survey routes have been shown in Table 4.10 and height of the bridges was referred from Google Earth (https://earth.google.com/web/).

Table 4.10: Bridges encountered in survey routes and their heights

Bridges encountered in survey routes	**Height (m)**
Acharya Jagadish Chandra Bose Road Flyover	13
Alipore Zoo Bridge	10
Ambedkar Bridge	7
Bijon Setu	8
Chingrighata Flyover	9
Dhana Dhanye Setu	7
Durgapur Bridge	8
Garia Bridge	9
Gariahat Flyover	10
Gitanjali Road Flyover, Newtown	6
Jai Hind Setu	8
Karunamoyee Bridge	8
Maa Flyover	13
Munshi Ganj Canal Bridge	12
Nabadiganta Flyover	7
Newtown Box Bridge	8
Newtown Bridge	8
Sri Chaitanya Mahaprabhu Setu	11
Sukanta Setu	9
Taratala Flyover	8
Tollygunge Bridge	8
Ultadanga Flyover	8
Vidyapati Setu	10
VIP Bridge	8

Number of bridges encountered in different routes and respective RS and FL values have been shown in **Table 4.11**. In case of routes used for buses, estimated values for RS and FL were 1.09 mm/km and for 4W it was 1.36 mm/km.

Table 4.11: RS and FL values for different routes.



Route	Distance (km)	Height of Bridge (m)	No of Bridges	RS (Rise in m/km)	FL (Fall in m/km)
1	9.70	8	1	0.825	0.825
2	16.40	37	4	2.256	2.256
3	11.10	9	1	0.811	0.811
4	29.60	31	4	1.047	1.047
5	15.40	15	2	0.974	0.974
6	21.60	34	4	1.574	1.574
7	10.60	8	1	0.755	0.755
8	17.10	8	1	0.468	0.468
9	22.40	38	4	1.696	1.696
10	9.70	8	1	0.825	0.825
11	10.70	8	1	0.748	0.748
12	28.98	77	9	2.657	2.657
13	10.42	8	1	0.768	0.768
14	23.00	45	6	1.957	1.957
15	10.56	0	0	0.000	0.000
16	13.65	8	1	0.586	0.586
17	15.70	34	3	2.166	2.166

4.4.4 Estimating fuel consumption in motion:

Values used for average moving speed, roughness of road, rise and fall for both the vehicles have been shown in Table 4.12. Corresponding values of fuel consumption as estimated using equations 4.3 and 4.4 were 0.26 l/km and 0.05 l/km for buses and 4W respectively.

Table 4.12: Fuel consumption in motion

Parameters	**Bus**	**4W**
V: Average Moving Speed (km/h)	18.61	27.23
RG: Roughness of road (mm/km)	4500.00	4500.00
RS: Rise (m/km)	1.09	1.36
FL: Fall (m/km)	1.09	1.36
FC_m: Fuel Consumption at motion (ml/km)	257.04	47.92
FC_m**: Fuel Consumption at Motion (l/km)**	0.26	0.05

It was observed that while in motion, bus consumed approximately 420% more fuel as compared to 4W for moving same distance.

4.4.5 Estimating fuel consumption at idling:

In order to calculate fuel consumption at idling, percentage idling time, DC distance and DC duration data was used from developed DC. Fuel consumption rate at idling for bus and 4W was taken as 150 ml/10 min and 94 ml/10 min respectively (Kumar et al., 2015). Equations 4.7 – 4.9 were used to calculate fuel consumption at idling.

$$T_{idling} = \frac{T_i \times D_{DC}}{100} \tag{4.7}$$

$$FC = \frac{T_{idling} \times FCR_i / 10}{1000} \tag{4.8}$$

$$FC_{idling} = \frac{FC}{S_{DC}} \tag{4.9}$$

where, T_{idling} : Idling time for trip (min)
T_i : Percentage idling time (%)
D_{DC} : DC duration (min)
FC : Fuel consumption (l)
FCR_i : Fuel consumption rate at idling (ml/10 min)
S_{DC} : DC Distance (km)
FC_{idling} : Fuel consumption at idling (l/km)

Based on above equations, fuel consumption at idling was calculated as shown in Table 4.13.

Table 4.13: Fuel consumption at idling

Parameters	**Bus**	**4W**
T_i: % Idling Time	31.29	28.77
D_{DC}: Driving Cycle Duration (min)	60.08	58.96
T_i: Idling Time (min)	18.80	16.96
FCR_i: Fuel Consumption Rate in Idling (ml/10 min)	150.00	94.00
FC: Fuel Consumption (liter)	0.28	0.16
S_{DC}: Driving Cycle Distance (km)	12.81	19.06
FC_{idling} : **Fuel Consumption at Idling (l/km)**	0.02	0.01

4.4.6 Fuel Consumption from DC data:

Data obtained from Table 4.12 and 4.13 was used to calculate fuel consumption as shown in equation 4.10 and final results have been shown in Table 4.14.

$$FC_{DC} = FC_m + FC_{idling} \tag{4.10}$$

where, FC_{DC} : Fuel consumption from DC data (l/km)

FC_m : Fuel Consumption at motion (l/km)

FC_{idling} : Fuel Consumption at idling (l/km)

Table 4.14: Fuel consumption from DC data

Parameters	**Bus**	**4W**
FC_m: Fuel Consumption at Motion (l/km)	0.26	0.05
FC_{idling} : Fuel Consumption at Idling (l/km)	0.02	0.01
FC_{DC}: Fuel consumption from DC data (l/km)	0.28	0.06
FC_{DC}: Fuel consumption from DC data (kWh/km)	2.80	0.60
Corresponding Vehicle Mileage (km/l)	3.57	16.67

It may be observed that energy consumption (fuel consumption) obtained from DC data for bus (2.80 kWh/km) is in accordance with energy consumption obtained for diesel fueled Non AC ICE bus (2.60 kWh/km for 9m Diesel Non AC bus and 3.10 kWh/km for 12m Diesel Non AC bus). For 4W, energy consumption obtained from DC data (0.60 kWh/km) is less as compared to Ambassador Taxi (0.82 kWh/km) and Ola/Uber cabs (0.76 kWh/km).

4.5 Conclusion:

DC analysis is an integral part of energy consumption and emission estimation for vehicles. As the traffic composition, vehicle density and road congestion scenarios change over the regions, the importance of regional DCs become more and more eminent. The same was observed when KBDC, KEBDC and K4WDC were compared with other available DCs. Although the parameter values for developed DCs remained within range of available Indian DCs, its features varied with the other DCs. KBCD varied from IDC within the range of 1.05% to 89.41% whereas KEBCD varied within the range of 1.05% to 52.30%. Minimum and maximum deviations for K4WDC as compared to MIDC for passenger cars were 1.30% and 78% respectively. Clearly Indian legislative DCs were not able to properly represent the driving conditions of Kolkata. Furthermore, the estimation of fuel consumption from DC data revealed that mileage for bus was 3.57 km/l which was in accordance with mileage obtained for diesel fueled Non AC ICE bus from survey data (3.32 km/l – 3.96 km/l). In case of 4W, mileage estimated from fuel consumption (16.67 km/l) obtained from DC data was higher as compared to mileage of Taxi or

Ola/Uber cabs (10 km/l – 14 km/l) obtained from survey. This can be attributed to a trait amongst commercial vehicle operators, noticed during survey, to intentionally report lesser mileage for vehicles so that they can show higher fuel expenses and hence lower profit. This study conducted in Kolkata verified the impact of variations in driving conditions and traffic behavior based on regions and established the need for regional DCs.

Abbreviations:

µC	Microcontroller
A_{avg}	Average positive acceleration
A_{max}	Maximum positive acceleration
A_{rms}	Root Mean Square acceleration
BI	British Towed Fifth Wheel Bump Integrator
CC	Candidate Cycle
D_{avg}	Average deceleration
D_{DC}	DC duration
D_{max}	Maximum deceleration
FB	Fuel Based
FC	Fuel consumption
FC_{DC}	Fuel consumption from DC data
FC_{idling}	Fuel Consumption at idling
FC_{idling}	Fuel consumption at idling
FC_m	Fuel Consumption at motion

FCR_i	Fuel consumption rate at idling
FTP	Federal Test Procedure
GPS	Global Positioning System
IDC	Indian Driving Cycle
K4WDC	Kolkata 4 Wheeler Driving Cycle
KBDC	Kolkata Bus Driving Cycle
KEBDC	Kolkata Electric Bus Driving Cycle
KE_{n+}	Net positive kinetic energy
MC-MC	Markov chain Monte Carlo
MIDC	Modified Indian Driving Cycle
MT	Microtrip
N_s	Number of stops per km
NEDC	New European Driving Cycle
OBD	On Board Diagnostics
OBDC	Overall Bus Driving Cycle
RMS	Root Mean Square
S_{DC}	Driving Cycle Distance
SAPD	Speed Acceleration Probability Distribution
SD	Secure Digital
T_a	Percentage time in acceleration mode
T_c	Percentage time in cruising mode

T_{cr}	Percentage time in creeping mode
T_d	Percentage time in deceleration mode
T_i	Percentage idling time
T_{idling}	Idling time for trip
V_{avg}	Average speed
$V_{m_{avg}}$	Average moving speed
V_{max}	Maximum Speed
WLTC	World Harmonized Light Vehicle Test Cycle

Chapter 5

Scope of Energy Conservation in Road Transportation Vehicles and Pollution Estimation

5.1 Introduction:

The previous chapters helped in forming an idea about energy consumption pattern in mass transport in selected regions. Now, it is already known that there are two major concerns regarding energy: climatic changes pertaining to energy consumption, and depleting energy sources. Pollution is one of the major causes of climate change and Indian cities have managed to enter the list of top 20 most polluted cities in world as per Global Ambient Air Quality Database 2018 published by World Health Organization (WHO). As per World Air Quality Report 2021, 11 Indian cities have entered the list of 15 most polluted cities in South Asia (World Air Quality Report, 2021). Transport sector, being a major contributor in air pollution due to vehicular emissions, needs proper attention in this regard. Around 94.5% of CO_2 and 53.3% of CO emissions in India was attributed to road transport sector (Dutta and Jinsart, 2021). Again, as per World Air Quality Report, 2021, internal combustion engines in motor vehicles are responsible for 20% to 35% of urban $PM_{2.5}$ concentrations (World Air Quality Report, 2021). Still majority of vehicles plying the streets are conventional internal combustion engine (ICE) vehicles and this do not improve the situation. Ever increasing demand for transportation and increasing number of vehicles is making scenario worse. Motorized passenger activity in India has increased from 1700 billion pkm in 2005 to 3833 billion pkm in 2020 (Indian Transport Energy Outlook, 2022). Increased vehicular activities contribute to increased congestion. This in turn increases fuel consumption and hence pollution.

A lot of research has been done in the field of pollution from vehicular emissions. Ramachandra and Shwetmala (2009) estimated emissions from Indian transport sector and found that in the year 2003-2004, 258.10 Tg of CO_2 was emitted by the transport sector, out of which road transport sector contributed 94.5%. Maharashtra, Tamil Nadu, Gujarat, Uttar Pradesh, Rajasthan and Karnataka contributed 28.85 Tg, 26.41 Tg, 23.31 Tg, 17.42 Tg, 15.17 Tg, and 15.09 Tg of CO_2 respectively. Khanna et al. (2011) conducted a study in Delhi and found that 2W were major contributors of CO, HC, NO_X, and SO_2 and that the petrol driven vehicles were responsible for about 96% and 97% of CO and HC emissions from passenger transport. Pollution related studies have also been conducted in Kolkata. Ghose et al. (2004) conducted a vulnerability analysis for selected locations in North Kolkata and observed that all the locations were under stress due to pollution from vehicular emissions. Gupta (2014) estimated carbon footprint from use of road transport and observed that per capita footprint increased with income.

Such a situation depicts the necessity of looking into the pollution scenario due to road transport vehicles which has been addressed in the following section. After having formed an idea about energy consumption and pollution scenario, the later part of the study discusses the scope for energy conservation in subsequent sections.

5.2 Estimation of Pollution Loads from Load Transport Vehicles in Different Locations in West Bengal:

5.2.1 Emission Factors:

In order to understand the pollution scenario, vehicular emission per passenger per km was estimated with the help of emission factors for different vehicles. Emission factor of a vehicle is basically the quantity of pollutant emitted by the vehicle per km of distance travelled. Emission factors for different types of vehicles were assembled from available literature and have been shown in Table 5.1.

Table 5.1: Emission factors for different vehicles (g/km)

Pollutants	Bus (Diesel)	Taxi (Diesel)	MUV (Diesel)	Passenger Cars (Diesel)	Auto Rickshaw (LPG)	Auto Rickshaw (Diesel)
CO_2	515.20	208.30	255.980	148.760	90.590	131.610
CO	3.60	0.90	0.250	0.060	0.178	0.410
NO_X	12.00	0.50	0.670	0.280	0.011	0.510
CH_4	0.09	0.01	-	-	0.004	0.180
SO_2	1.42	10.30	-	-	-	0.029
PM	0.56	0.07	0.096	0.015	-	0.091
HC	0.87	0.13	0.190	0.080	0.030	0.140

Source: Dutta and Jinsart, 2021, ARAI Report, 2008, Majumdar, 2022

Emission factors for bus and taxi were referred from Dutta and Jinsart (2021). Values for MUV passenger cars and auto rickshaws (LPG and Diesel) have been referred from ARAI report 2008 (ARAI, 2008) and Majumdar (2022). Emission factors for passenger cars (diesel) were used to calculate emissions for Ola/Uber cabs and Tata Magic whereas values for multi utility vehicle (MUV) (diesel) were used to calculate the same for Mahindra Bolero. It may be observed from

Table 5.1 that emission factors for CH_4 are missing for MUV and passenger cars, SO_2 emission factors are missing for MUV, passenger cars, and LPG auto rickshaws and PM emission factors are missing for LPG auto rickshaws. Now, there are literatures available, for example Ramachandra and Shwetmala (2009) and Dutta and Jinsart (2021), where emissions factor for these pollutants are available for vehicles like cars and jeeps which could have been used for this study. However engine capacity of the vehicles, year of manufacture, type of fuel used and emission standards based on which these emission factors were obtained were not clear enough. Using these emission factors would mean generalizing a group of vehicles with different engine capacity, using different fuels, having different year of manufacture and emission standards. Emission factors used in this study gave a clearer classification in this regard and hence could represent the actual emissions in a better manner.

5.2.2 Estimation of Emission Load per Passenger-km

Based on these emissions factors and equivalent passenger load, vehicular emissions per passenger-km were calculated using equation 5.1.

$$E_{p,v} = \frac{EF_{p,v}}{P_{eq,v}} \tag{5.1}$$

where, $E_{p,v}$ = Emission of pollutant type 'p' from vehicle type 'v'

$EF_{p,v}$= Emission factor of pollutant type 'p' from vehicle type 'v'

$P_{eq,v}$ = Equivalent passenger load for vehicle type 'v'

For example, emission factor for CO_2 for diesel bus is 515.20 g/km (Table 5.1) and equivalent passenger load for a 9m bus 43.55 (Table 3.5). Therefore CO_2 emission per passenger-km for a 9m bus can be calculated as

$$E_{\mathrm{CO}_2,9m\ bus} = \frac{EF_{\mathrm{CO}_2,9m\ bus}}{P_{eq,9m\ bus}} \tag{5.2}$$

$$= \frac{515.20}{43.55} = 11.83 \qquad \text{g/pkm}$$

Again, emission factor for HC for LPG auto rickshaw is 0.03 g/km (Table 5.1) and equivalent passenger load for the same is 1.75 (Table 3.6). Therefore CO_2 emission per passenger-km for a LPG auto rickshaw can be calculated as

$$E_{\mathrm{HC}\,,Auto\ rickshaw\ (LPG)} = \frac{EF_{\mathrm{HC}\,,Auto\ rickshaw\ (LPG)}}{P_{eq\,,Auto\ rickshaw\ (LPG)}} \tag{5.3}$$

$$= \frac{0.03}{1.75} = 0.0171 \qquad \text{g/pkm}$$

Emissions in grams of pollutant per passenger-km, obtained from similar calculations as shown above, for different vehicles have been shown in Figures 5.1-5.7. It can be observed from Figure 5.1 that CO_2 emissions were maximum for Ambassador Taxis and minimum for buses. CO_2 emissions for 3Ws and other 4Ws except for Ambassador Taxi were in similar range (49.59 g/pkm – 51.77 g/pkm). In case of CO (Figure 5.2), the emissions varied within the range of 0.02 g/pkm and 0.3 g/pkm with the maximum values being recorded for Ambassador Taxi and minimum values being recorded for Ola/Uber cabs and Tata Magic. 9m bus recorded maximum NO_X emissions (0.28 g/pkm) followed by 12m bus (0.24 g/pkm) while LPG driven auto rickshaws recorded the least (0.01 g/pkm) (Figure 5.3). HC emissions for diesel auto rickshaws (0.0532 g/pkm) were more as compared to the 4Ws and buses whereas LPG auto rickshaws had the least (0.0171 g/pkm) (Figure 5.4). Diesel auto rickshaws reported maximum PM emissions (0.0346 g/pkm) followed by Ambassador Taxi (0.0233 g/pkm) whereas Ola/Uber cabs and Tata Magic from the passenger car segment reported minimum emissions (0.005 g/pkm) (Figure 5.5). CH_4 emissions reported for diesel auto rickshaws (0.0684 g/pkm) and SO_2 emissions for Ambassador Taxis (3.433 g/pkm) were much higher as compared to the other vehicles in the same emission category (Figure 5.6 and 5.7 respectively).

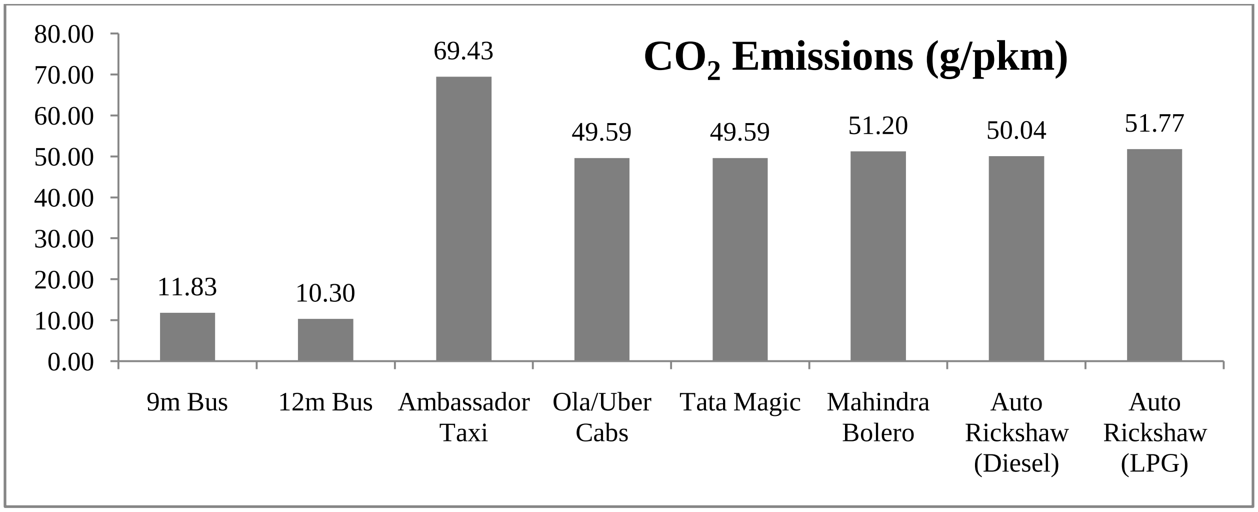


Figure 5.1: CO_2 emissions from different types of vehicles

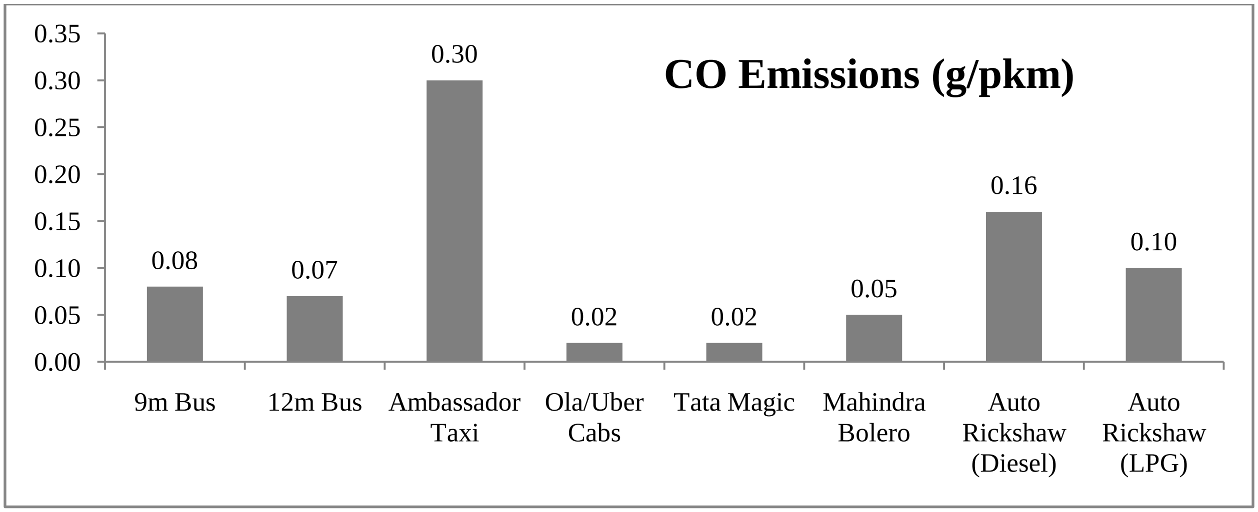


Figure 5.2: CO emissions from different types of vehicles

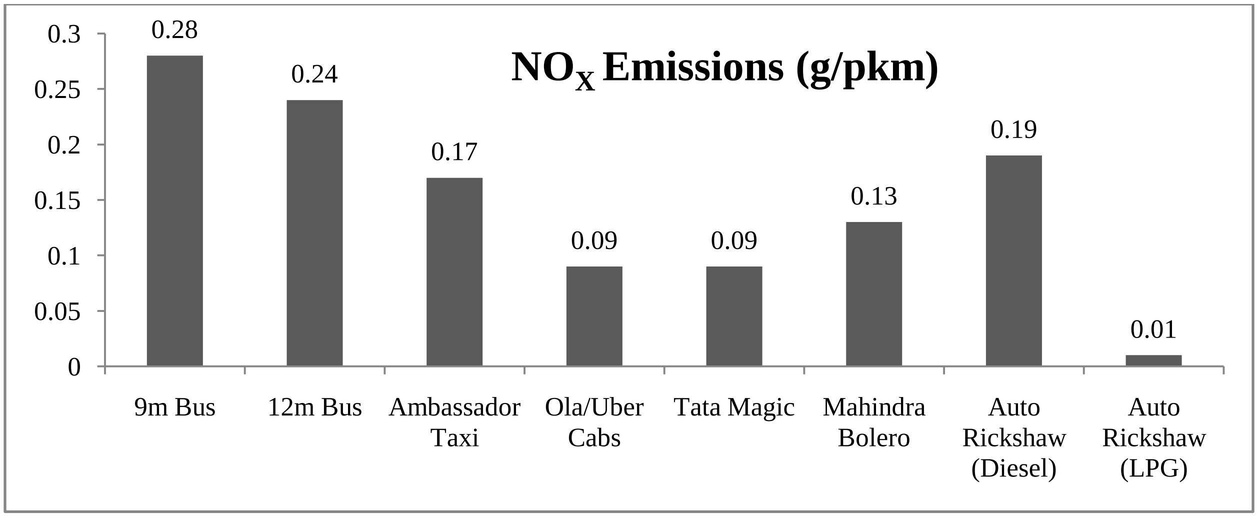


Figure 5.3: NO_X emissions from different types of vehicles

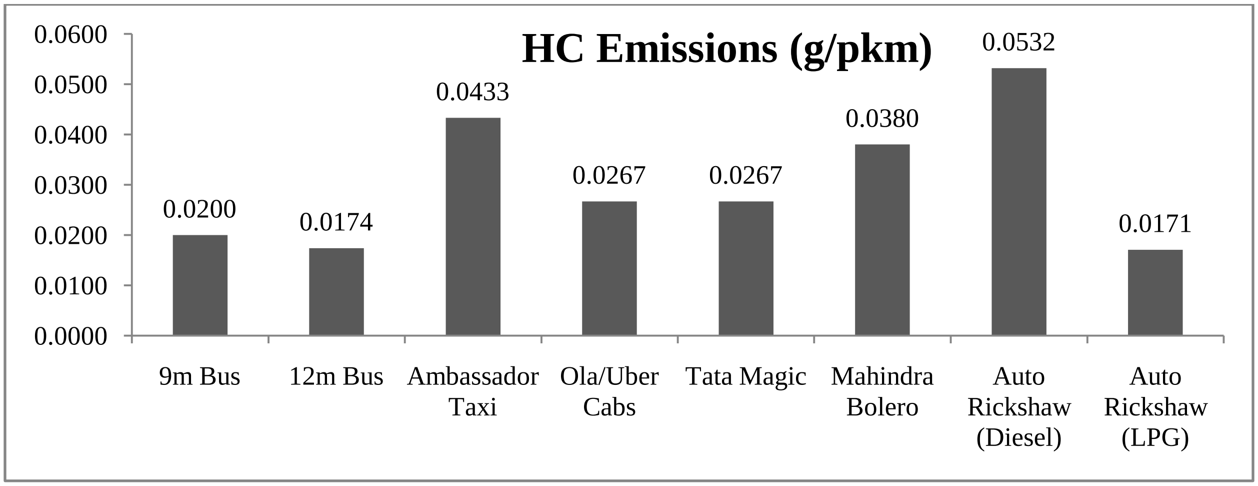


Figure 5.4: HC emissions from different types of vehicles

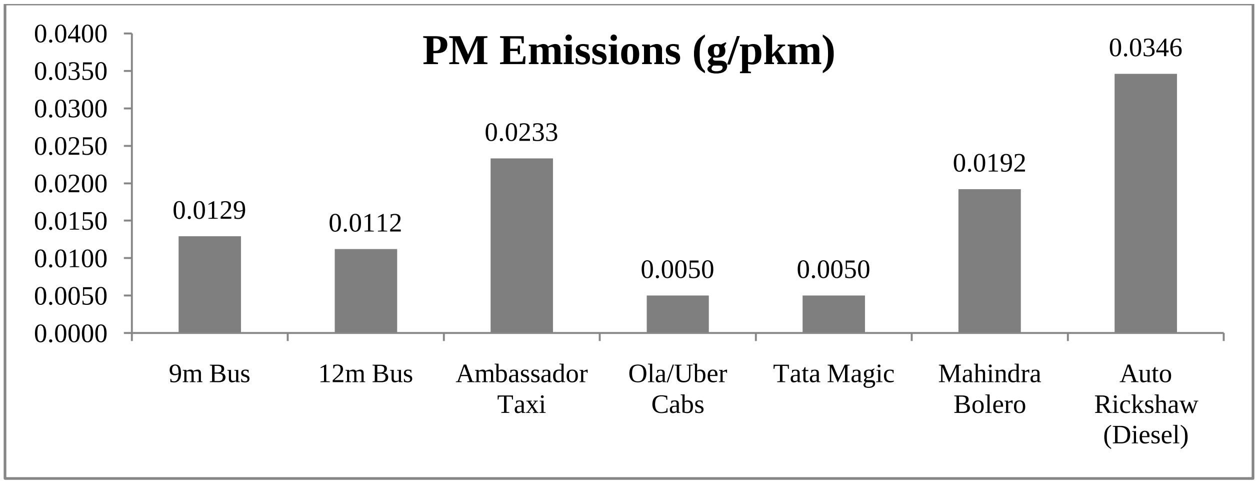


Figure 5.5: PM emissions from different types of vehicles

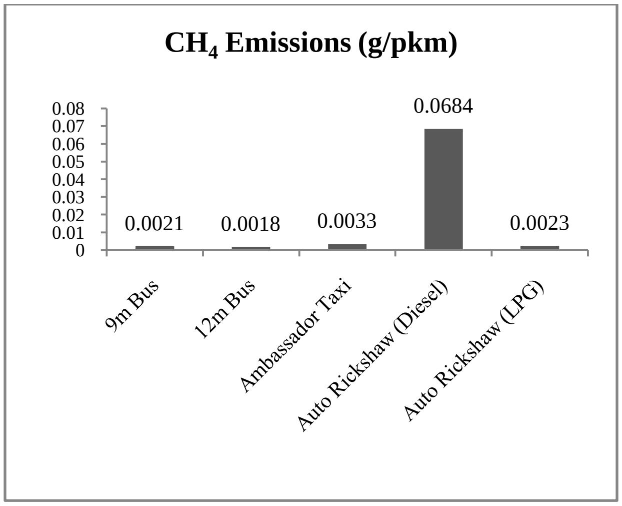


Figure 5.6: CH_4 emissions from different types of vehicles

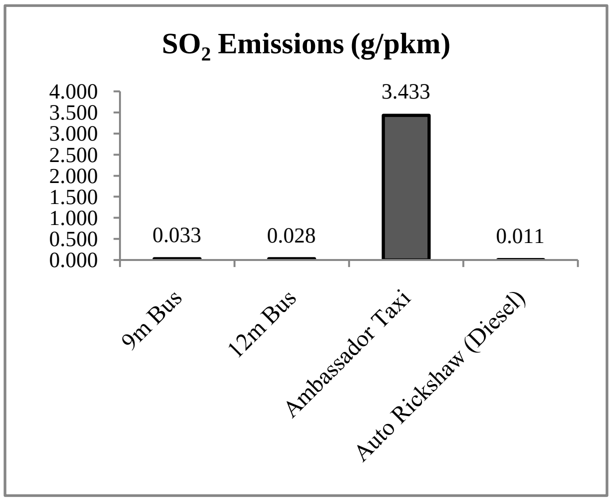


Figure 5.7: SO_2 emissions from different types of vehicles

Unlike other vehicles, Vano are assembled from low cost diesel fuel engines meant for irrigation purposes. Emission factors for this vehicle were derived from emissions of agricultural diesel pumps. Adhikari et al. (2019) studied these pumps and obtained emission factors as shown in Table 5.2.

Based on this data, emission factors for Vano were calculated as shown in equation 5.4.

$$EF_p = \frac{\sum_{i=1}^{n} EF_{p,pump\ i} \big/ n}{M_v} \tag{5.4}$$

where, EF_p: Emission factor for pollutant type 'p' (g/km)

$EF_{p,pump\ i}$: Emission factor for pollution type 'p' for i^{th} number of pump (g/l)

n: Number of pumps

M_v: Mileage of Vano (km/l)

Table 5.2: Emission factors of agricultural diesel pumps

Pump ID	**Emission Factor CO_2 (g/l)**	**Emission Factor CO (g/l)**	**Emission Factor $PM_{2.5}$ (g/l)**	**Emission Factor Black Carbon (g/l)**
Pump 1	2592.00	39.10	3.72	0.46
Pump 2	2359.00	183.00	58.51	4.46
Pump 3	2462.00	121.40	5.06	0.96
Pump 4	2145.00	317.40	80.33	5.86
Pump 5	2506.00	93.10	4.09	1.05
Pump 6	2523.00	82.40	10.08	0.97
Pump 7	2481.00	106.80	6.46	3.11
Pump 8	2471.00	110.00	28.06	5.76

Source: Adhikari et al., 2019

Emission factor obtained for Vano has been shown in Table 5.3 and emission per passenger-km has been shown in Figure 5.8. It can be observed that CO_2 contribution per passenger-km (23.26 g/pkm) for Vano was much higher as compared to other emissions.

Table 5.3: Emission factors for Vano

Pollutants	CO_2	CO	$PM_{2.5}$	Black Carbon
Emission Factors (g/km)	81.413	4.388	0.818	0.094

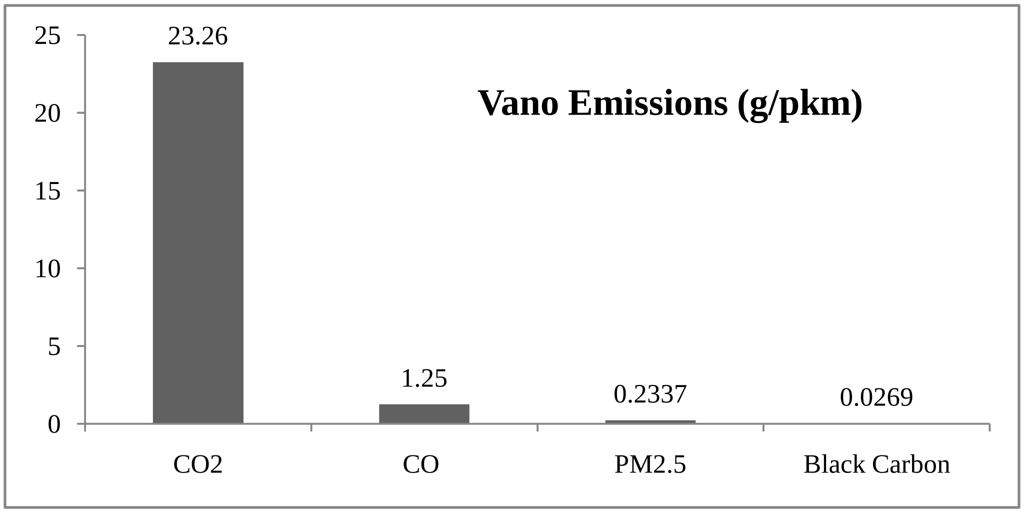


Figure 5.8: Emissions from Vano

5.2.3 *Total Emission Loads from Different Road Vehicles in West Bengal*

Average distance travelled per day by different vehicles in different locations as obtained from the survey data (Tables 3.5-3.7) has been shown in Figure 5.9.

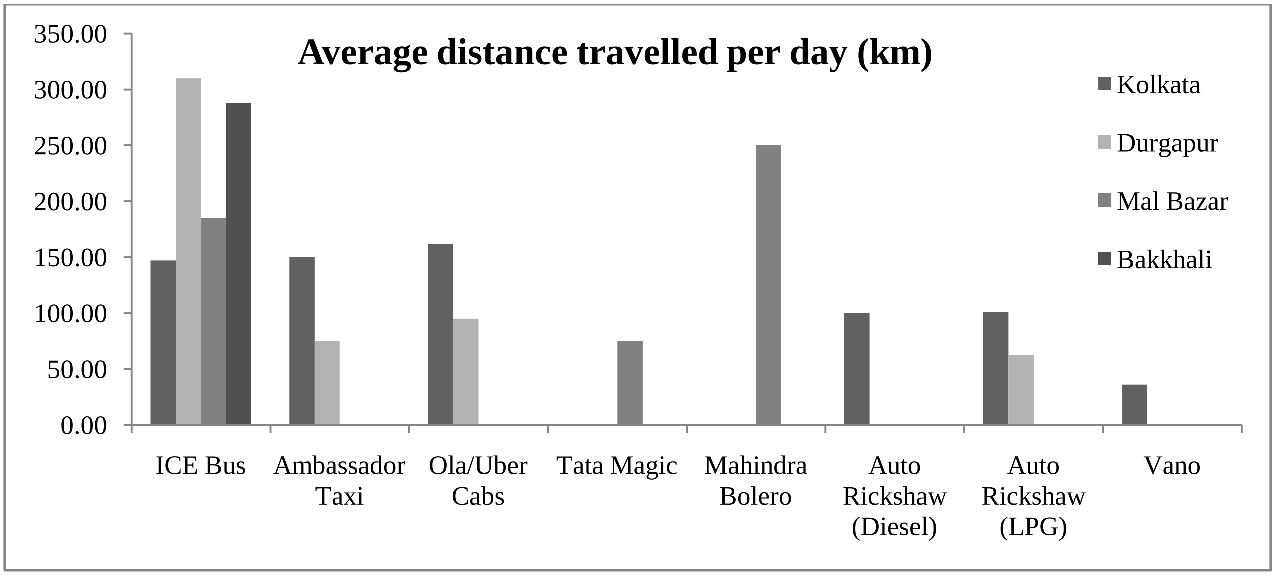


Figure 5.9: Average distance travelled per day

Based on this data, total emissions per day per ICE vehicle have been calculated using equation 5.5.

$$E_{p,v} = EF_{p,v} \times D_v \tag{5.5}$$

where, $E_{p,v}$ = Emission of pollutant type 'p' from vehicle type 'v'

$EF_{p,v}$= Emission factor of pollutant type 'p' from vehicle type 'v'

$P_{eq,v}$ = Distance travelled per day by vehicle type 'v'

For example, emission factor for CO_2 for diesel bus is 515.20 g/km (Table 5.1) and distance travelled per day by a bus is 147.025 km (average of distance covered per day values for diesel fueled buses from Table 3.5). Therefore CO_2 emission per bus per day can be calculated as

$$E_{\mathrm{CO}_2,bus} = EF_{\mathrm{CO}_2,bus} \times D_{bus} \tag{5.6}$$

$$= 515.20 \times 147.025 = 75747.28 \quad \text{g/day}$$

Again, emission factor for HC for LPG auto rickshaw is 0.03 g/km (Table 5.1) and distance travelled per day by a LPG auto rickshaw is 101 km (average of values from Table 3.6). Therefore HC emission per LPG auto rickshaw per day can be calculated as

$$E_{\mathrm{HC}\ ,Auto\ rickshaw\ (LPG)} = EF_{\mathrm{HC}\ ,Auto\ rickshaw\ (LPG)} \times D_{Auto\ rickshaw\ (LPG)} \quad (5.7)$$

$$= 0.03 \times 101\ = 3.03 \quad \text{g/day}$$

Based on similar calculations, emission loads of different vehicles in different locations of West Bengal have been estimated and shown in Tables 5.4-5.7.

Table 5.4: Emissions in Kolkata (g/day)

Pollutants	**ICE Bus**	**Ambassador Taxi**	**Ola/Uber Cabs**	**Auto Rickshaw (Diesel)**	**Auto Rickshaw (LPG)**	**Vano**
CO_2	75747.28	31245.00	24050.03	13161.00	9149.59	2930.85
CO	529.29	135.00	9.70	41.00	17.98	157.98
NO_X	1764.30	75.00	45.27	51.00	1.11	0.00
CH4	13.23	1.50	0.00	18.00	0.40	0.00
SO_2	208.78	1545.00	0.00	2.90	0.00	0.00
PM	82.33	10.50	2.43	9.10	0.00	29.45*
HC	127.91	19.50	12.93	14.00	3.03	3.39[#]

*: $PM_{2.5}$ emission; [#]: Black Carbon emission

Table 5.5: Emissions in Durgapur (g/day)

Pollutants	**ICE Bus**	**Ambassador Taxi**	**Ola/Uber Cabs**	**Auto Rickshaw (LPG)**
CO_2	159712.00	15622.50	14132.20	5661.88
CO	1116.00	67.50	5.70	11.13
NO_X	3720.00	37.50	26.60	0.69
CH4	27.90	0.75	0.00	0.25
SO_2	440.20	772.50	0.00	0.00
PM	173.60	5.25	1.43	0.00
HC	269.70	9.75	7.60	1.88

Table 5.6: Emissions in Mal Bazar (g/day)

Pollutants	ICE Bus	Tata Magic	Mahindra Bolero
CO_2	95312.00	11157.00	63995.00
CO	666.00	4.50	62.50
NO_X	2220.00	21.00	167.50
CH4	16.65	0.00	0.00
SO_2	262.70	0.00	0.00
PM	103.60	1.13	24.00
HC	160.95	6.00	47.50

Table 5.7: Emissions in Bakkhali (g/day)

Pollutants	ICE Bus
CO_2	148377.60
CO	1036.80
NO_X	3456.00
CH4	25.92
SO_2	408.96
PM	161.28
HC	250.56

Having estimated the emissions per day for different locations, it has to be kept in mind that in case of Durgapur, Mal Bazar and Bakkhali, routes of some buses (long distance bus) extend beyond the limits of surveyed locations. Similar situations can be observed for Mal Bazar where tourists sometimes use the vehicles (Mahindra Bolero) to travel to places outside the designated regions of survey. It was not possible to clearly identify the distance covered by vehicles within and outside the surveyed locations from obtained data. Hence, emissions estimated per day per vehicle, although correct, cannot be completely attributed to corresponding locations for these particular vehicles. In other words, some part of this emission is spread in regions outside the surveyed locations.

5.3 Scope of Energy Conservation:

The sole purpose of studying energy consumption pattern is to identify ways in which energy can be conserved. Having studied the energy consumption pattern and pollution scenario, it is time to have a look at ways in which energy can be conserved, and how the knowledge obtained from the study so far can be utilized to achieve the same. There are various ways in which energy can be conserved. Some of these are based on implementation of EVs, advancement in technologies such as improvements in ICE technology, switching to cleaner fuels (LPG, CNG), some are based on change in policies (implementing strict emission norms), some are based on changes in human behavior (efficient utilization of vehicles, shifting towards mass transit etc.). Different methods for energy conservation in road transport vehicles have been discussed in the following section. Some of these methods have been studied under the scope of this research work while other utilizes the knowledge gained from this study.

5.3.1 Study on Introduction of EVs as a Replacement of ICE Vehicles:

Introduction of EVs in the vehicle fleet and replacing ICE vehicles by the same is the most popular mode of addressing the pollution as well as the consumption scenario. A study conducted by Majumdar et al. (2015) on the environmental and economic impacts of EVs in Kolkata revealed that by replacing 2% of ICE buses, taxis and auto rickshaws in the city, 4253710 l of diesel and 1188440 l of LPG consumption could be reduced in one year. Also corresponding reduction in emissions per day was reported to the tune of 26.27 tons of CO_2, 0.972 tons of SO_2, 0.209 tons of NO_X, 0.132 tons of CO, 0.0021 tons of CH_4, 0.024 tons of HC and 0.014 tons of PM per day. Faster Adoption and Manufacturing of Hybrid & Electric Vehicles (FAME), a Government of India initiative, which is an integral part of National Electric Mobility Mission Plan (NEMMP) in India, was introduced to reduce the use of fossil fuel powered vehicles. The first phase of FAME was from 2015 to 2019 and the second phase was from 2019 to 2022, with a target of introducing 30% EVs by 2030 (https://pib.gov.in/, https://fame2.heavyindustries.gov.in, https://www.financialexpress.com). The scheme included subsidies for EVs meant for privately owned vehicles, alongside different policies and funding programs for vehicles of mass transit. Although government is subsidizing the purchase of private EVs, it has to be understood that as long as EVs represent only a small portion of the total vehicle fleet, the tailpipe emissions of ICE vehicles in congested roads and slow moving traffic will nullify the benefits of the EVs. A congestion free road with smooth moving traffic can be achieved only when commuters choose mass transit over personalized vehicles. A more effective approach is for the commuters to switch to electric mode of mass transit such as eBuses. To achieve this, there should be adequate availability of eBus services that can enable commuters to reach their destination within a reasonable time. Government has taken a sensible approach in introducing eBuses to address this scenario. Around 220 eBuses under FAME I are operating in eight cities and 2450 eBuses have been procured as of November 2020 out of 5595 buses allotted under FAME II (https://wri-india.org). An attempt was made to study the on-road performance of EVs as compared to ICE vehicles which have been discussed in the following section.

5.3.1.1 Comparative Study of On-road Performance for EVs and ICE vehicles

A study was conducted in Kolkata to analyze the on-road operational features of EVs in real time traffic scenario as compared to ICE vehicles. Despite the best efforts of Government, the penetration of electric 4 wheelers (e4Ws) in the city is still very low and these vehicles were unavailable for experimental study. Majumdar et al. (2022) studied the performance of electric 3 wheelers (e3Ws) and hence this study concentrated on buses. For this purpose, two types of buses were chosen: 9m ICE diesel bus and 9m AC eBus. Images of these buses have been shown in Figure 5.10 and specifications have been shown in Table 5.8. 9m AC eBus was chosen since the numbers of 9m buses plying the streets were more as compared to 12m AC eBus and these buses were easily available. Also these buses were able to ply the narrower unplanned streets of the locality which were inaccessible to the 12m eBuses. Choosing a Non AC eBus was not an option because all the eBuses belonged to AC variant. Although 9m AC ICE buses are available, they are negligible in number. Hence 9m Non AC ICE bus was chosen as a counterpart for 9m AC eBus since it was assumed that these buses would represent real world driving scenarios better on behalf of ICE buses.

S31 bus route (Figure 5.11) was selected for the study which originated at Janakalyan bus stop near Behala Chowrasta and ended at Jadavpur 8B bus stand. The route passed through the locations of Muchipara, Shiriti, Tollygunge Metro Station, Anwar Shah Crossing and Jadavpur Police Station and stretched over a distance of 13 km.

GPS data logger as mentioned in chapter 4 was used to obtain data. Data for both the buses were obtained during morning peak hours so that it can reflect performance of the buses under similar traffic conditions. Speed profiles obtained from data for both the buses have been shown in Figures 5.12 and 5.13 and driving parameters have been shown in Table 5.9.

Figure 5.10: 9m Non AC ICE bus and 9m AC eBus

Table 5.8: Specifications for buses

Specifications	**ICE Bus**	**Electric Bus**
Fuel Type	Diesel	Electricity
Gross Vehicle Weight	10200 kg	10200 ± 300 kg
Engine / Motor Rating	92 kW @ 2600 rpm	245 kW
Maximum Torque	390 Nm @ 1000 – 2200 rpm	3000 Nm
Fuel Tank / Battery Capacity	120 L	125 kWh
Seating Capacity	41+D	31+D
Vehicle Length	9750 mm	9200 mm

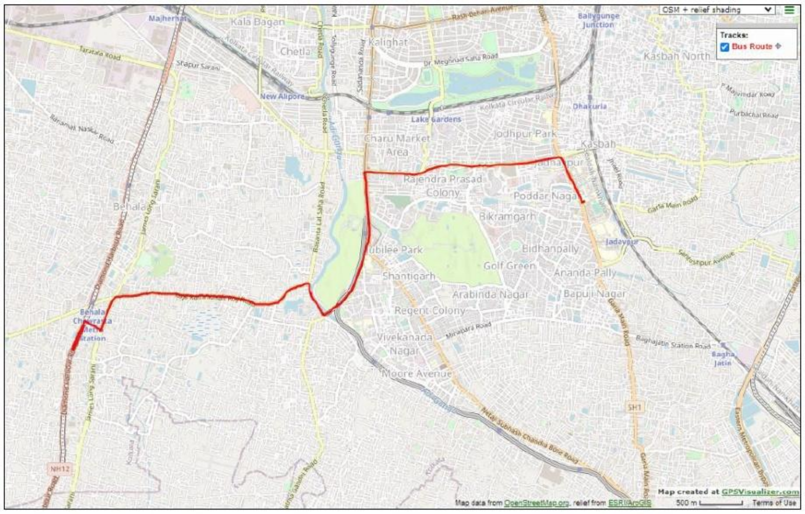


Figure 5.11: Survey route map (courtesy: https://www.gpsvisualizer.com/)

On analyzing the data it was observed that eBus displayed better average speed, average moving speed and maximum speed as compared to ICE bus. The average moving speed of an eBus was 36.91% more than that of an ICE bus whereas the average speed was 19.48% more. Percentage idling time for the eBus is 28.6% more as compared to the ICE bus. This can be attributed to the fact that although data was collected at the same peak hours and same route, the halts at the different traffic signals encountered might vary as the buses were not running parallel. Also the halts due to boarding and alighting of passengers varied in different trips. The maximum speed achieved by the eBus and its RMS acceleration is 3.32% and 12.14% more than the ICE bus respectively.

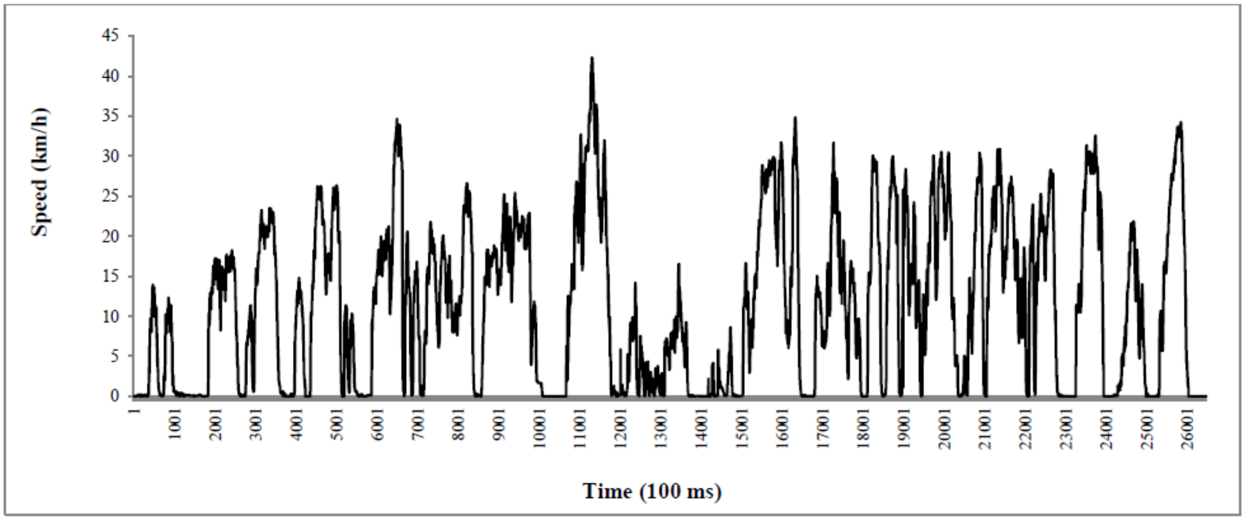


Figure 5.12: Speed profile for ICE bus

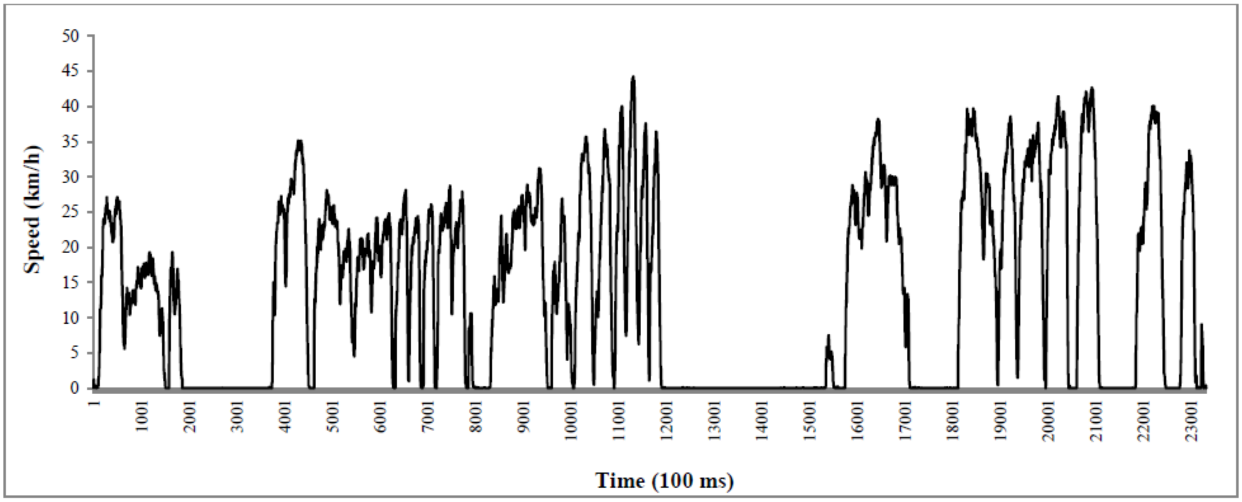


Figure 5.13: Speed profile for eBus

Table 5.9: Variation in driving parameters

Parameters	ICE Bus	AC Electric Bus
Average moving speed (km/h)	16.35	22.38
Average speed (km/h)	11.31	13.51
Maximum speed (km/h)	42.19	43.59
Percentage idling time	30.80	39.61
Percentage time in cruising mode	11.42	11.32
Percentage time in creeping mode	6.45	3.14
Percentage time in deceleration mode	23.61	20.76
Percentage time in acceleration mode	25.84	24.97
Maximum acceleration (m/s^2)	4.70	3.77
Maximum deceleration (m/s^2)	-5.38	-3.23
Average acceleration (m/s^2)	0.40	0.42
Average deceleration (m/s^2)	-0.42	-0.48
RMS acceleration (m/s^2)	0.57	0.64

Although it spent more time in idling mode, time spent in creeping mode was much lesser as compared to its counterpart and despite the variation in the idling time, the eBus exhibited higher average speed in similar route conditions. The overall performance of both the buses were comparable and in some instances eBus performed better as compared to ICE bus. Hence as far as short distance intra city trips are concerned, eBus can be a worthy replacement for ICE bus. Whether these buses can perform similarly in long distance routes need to be studied further.

5.3.1.2 Comparative Study on Energy Consumption of EVs and ICE vehicles

In order to understand the energy consumption for eBuses, it was necessary to have a look into the charging scenario of these vehicles. Primary survey helped in understanding the real world charging scenario for eBuses at the State Road Transport Undertaking (SRTU) operated bus depots in Kolkata. Both fast charging and normal charging facilities were available in the depot where, on an average, 7 different buses were recharged daily. Most of the buses were recharged at least twice in a day whereas the minimum and maximum number of charging events recorded for a particular bus was 1 and 4 respectively. Average electrical units consumed for a single charging event was 54.93 kWh. Table 5.10 illustrates the charging time, number of charging events and electrical energy consumption as obtained from real world operating scenario.

Table 5.10: Charging details for eBuses in a charging station

Date	**Total Charging Time (minutes)**	**Average Charging Time per Bus (minutes)**	**Number of Charging Events**	**Electricity Consumed for Charging (kWh)**
Day 1	1259	89.93	14	842.59
Day 2	635	79.38	8	424.78
Day 3	1020	78.46	13	576.2
Day 4	1245	88.93	14	837.3
Day 5	1309	100.69	13	759.14
Day 6	890	74.17	12	645.33

The daily average duration for which the chargers operated at the depots was 1059 minutes and average charging time per bus was approximately 85 minutes. The average number of charging events per day was recorded to be 12. Energy consumption and corresponding distance travelled for different eBuses in between two consecutive charging events has been shown in Figure 5.14. Average distance travelled by an eBus between two consecutive charging was evaluated as 61.21 km. It can be observed that eBuses were sometimes plugged in to their charging stations after plying a distance of just 25 km when range of autonomy for 9 m and 12 m eBuses was observed to be almost 103 km and 155 km respectively.

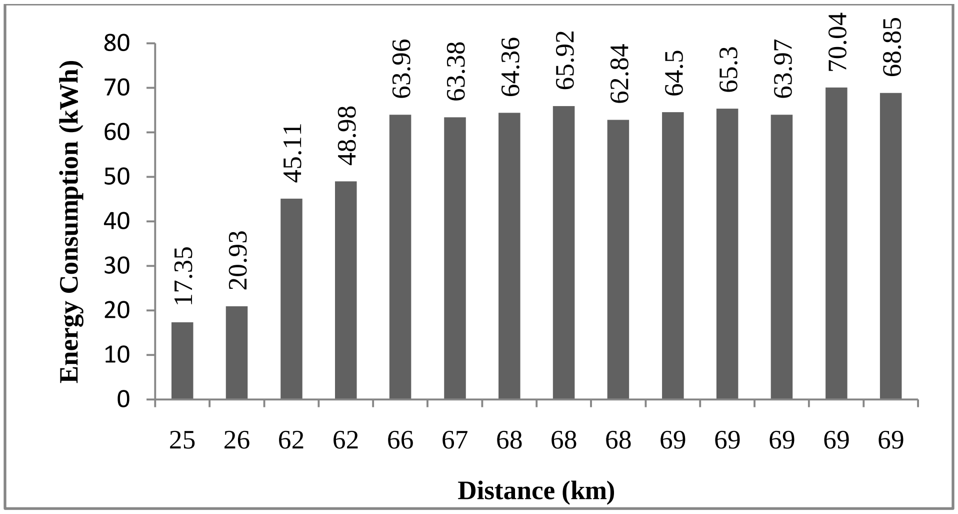


Figure 5.14: Variation in energy consumption with distance

The minimum and maximum state of charge (SOC) recorded at the bus depots before initiating a charging event was 10% and 80% respectively. Opportunity charging at a higher SOC illustrated the charging behavior of vehicle operators arising out of range anxiety or prior knowledge regarding lack of charging infrastructure. This can be attributed to the psychology of bus operators in on road performance of the vehicles. It may be observed that the minimum and maximum energy consumed for same distance traversed varied by 9.5%. This variation in energy consumption can be accredited to variation in on-road traffic characteristics, time of journey (peak and off-peak hours) and variation in vehicle loading as also observed by Dreier et al. (2019). The average value of energy consumption as obtained from data turned out to be 0.97 kWh/km, which is also in accordance with data reported in literature (e-bus-case-study-Kolkata-Clarifications). From the survey test results the minimum and maximum limits for energy consumption of eBuses were observed to be 0.66 kWh/km and 1.53 kWh/km respectively. In Table 5.11, a comparative overview of energy consumption for battery eBuses have been presented based on the present study and values obtained from literature.

Table 5.11: Energy consumption comparison for eBuses

Source	Energy Consumption (kWh/km)
Majumder et al. (a)	1.57
Vijaykumar et al. (b)	0.8 – 2.94
Present Study	0.66 – 1.53

(a) Majumder et al., 2019; (b) Vijaykumar et al., 2021

The probable reduction in energy consumption and specific energy consumption per vehicle in different vehicle categories that can be achieved due to the implementation of EVs has been shown in Table 5.12. In case of buses, the reduction in energy consumption and specific energy consumption was more than 72% whereas for 4Ws it was more than 85%. 3Ws showed a reduction of more than 74% for the same. Clearly on a vehicle to vehicle replacement basis, as far as energy consumption is considered, EVs of all segment (bus, 4W and 3W) proved to be better as compared to ICE vehicles. However energy consumption is not the only factor that is needed to be analyzed as far as EV implementation is concerned. Although EVs have zero tailpipe emissions, based on the energy source of the EV charging facility, the plant level emissions need to be analyzed. An attempt has been made to analyze the same in the following section.

Table 5.12: Comparison in reduction of energy consumption and specific energy consumption

Parameters	ICE Bus	eBus	% Reduction	4W	e4W*	% Reduction	3W	e3W#	% Reduction
Average Energy Consumption (kWh/km)	3.62	0.97	73.18	0.92	0.13	86.22	0.37	0.08	79.75
Average Specific Energy Consumption (kWh/pkm)	0.08	0.02	72.90	0.28	0.03	88.19	0.17	0.04	74.07

*Source: (Saxena et al., 2014); #Source: (Majumdar, 2022)

5.3.1.3 Study on Pollution Scenario Related to EVs

The fact that EVs are better than ICE vehicles as far as energy consumption is concerned cannot be denied. Due to its zero tailpipe emissions it is also a better option for mitigating environmental impacts due to vehicular emissions in the urban conditions. But these vehicles need to be charged and the electricity needed for charging in this country comes mainly from fossil fuel based sources. So instead of polluting the cities, these vehicles are responsible for emissions at the power plant level which needs to be analyzed. Donateo et al. (2015) studied the potential of electric cars considering emission of CO_2 and other pollutants using energy mix data and emission factors. Huo et al. (2015) studied lifecycle greenhouse gas emissions of EVs in US and China. von Brockdorff and Tanti (2017) conducted a comparative study on CO_2 emissions of EVs and ICE vehicles in Malta. Wu and Zhang (2017) studied the impact of energy mix on CO_2 emission of EVs. It was observed that utilization of EVs would increase $PM_{2.5}$ and NO_X emissions in India. Choma et al. (2020) assessed the health impacts of electric vehicles through air pollution in the United States and inferred that substituting conventional ICE vehicles with EVs in urban areas is clearly a better choice which led to large benefits even when these vehicles were charged exclusively from fossil fueled power plants. Sharma and Chandel (2020) studied the pollution impacts of EVs in Indian context and observed that CO_2 emissions would decrease by 29% for all vehicles except buses where the emissions would increase by 47%.

Considering the context of India, thermal power represented 80.1% of generation share in 2016 (Sharma and Chandel, 2020). Although Government of India has planned to increase the installed capacity of renewable sources, and in future the share of renewable in energy mix will increase, in case of this study it has been assumed that the main source of energy for electricity generation is hard coal. Based on this assumption, emission factors for grid during a charging event were referred from CO_2 Baseline Database (CO_2 Baseline Database for the Indian Power Sector) and Sharma and Chandel (2020), and the environmental impacts for different pollutants were studied. Emission factor used for this study has been shown in Table 5.13. Calculation model for environmental impacts of various pollutants have been referred from Weldon et al. (2016) and Majumdar (2022) and derived using equations 5.8 and 5.9.

Table 5.13: Emission factor for electricity produced from hard coal (g/kWh)

Pollutants	CO_2	CO	NO_X	$PM_{2.5}$	HC
Emission Factors	910.364	0.396	1.947	0.141	7.56E-05

$$X_p = EC \times GEF_p \times CF_{GL} \times CF_{CL} \tag{5.8}$$

$$X_p = EC \times GEF_p \times CF_{GL} \tag{5.9}$$

where,

X_p= Environmental impact of pollutant type ‘p’ (g)

EC = Energy consumed in charging event (kWh)

GEF_p= Emission factor of pollutant type ‘p’ for grid during charging event (g/kWh)

CF_{GL}= Dimensionless correction factor accounting for grid transmission and distribution losses

CF_{CL} = Dimensionless correction factor accounting for charging losses.

Equation 5.8 was used for vehicle category of bus and e4W whereas equation 5.9 was used for e3Ws. The reason behind this is that the method in which charging energy is measured for e3Ws takes into account the charging efficiency. For this study, value for CF_{GL} have been considered to be 1.08 and has been referred from Calcutta Electric Supply Corporation (CESC) (CESC Investor Presentation, 2020). Value for CF_{CL} has been considered 1.1 and has been referred from Weldon et al. (2016). Considering the values for EC to be energy consumed for travelling a distance of 1 km, X_p would be expressed in grams of pollutants per km (g/km). From this X_p per passenger-km may be obtained as shown in equation 5.10.

$$X_{p,per\ passenger\ -km} = \frac{X_p}{P_{eq}} \tag{5.10}$$

where, $X_{p,per\ passenger\ -km}$ = Environmental impact of pollutant type 'p' (g/pkm)

P_{eq} = Equivalent passenger load

Emissions per passenger-km obtained for different pollutants at plant level due to charging of EVs from electricity generated from hard coal have been shown in Table 5.14. It may be observed that CO_2 emissions are maximum and HC emissions are minimum when overall EV segment is considered. In case of all the pollutants, emissions from the 3W segment were maximum and emissions from 12m buses were minimum.

Figures 5.15-5.17 shows the comparison of emissions per passenger-km for CO_2, CO and NO_X between ICE vehicles and EVs. For ICE vehicles, emission factor for PM (Table 5.1) was available which takes into account both PM_{10} and PM $_{2.5}$ and for EVs emission factor for $PM_{2.5}$ was available. Estimation of pollutants was done based of these emission factors. Comparing these two would not be right since it could lead to erroneous conclusions. Hence the comparison plot for this emission segment was left out.

Table 5.14: Emission of pollutants (g/pkm) for EVs

Vehicle Category	**CO_2**	**CO**	**NO_X**	**$PM_{2.5}$**	**HC**
9m Bus	20.90390	0.01048	0.05152	0.003731	2.0004E-06
12 Bus	18.20729	0.00913	0.04487	0.003250	1.7424E-06
4W (High Power)	23.08760	0.01157	0.05690	0.004121	2.2094E-06
4W (Low Power)	26.27860	0.01317	0.06477	0.004690	2.5148E-06
3W	36.90090	0.01850	0.09094	0.006586	3.5313E-06

.Also HC emission levels for EVs were negligible as compared to ICE vehicles (to the tune of 10^{-4}) and hence comparison plot for this emission segment was left out too. From Figure 5.15 it may be observed that although CO_2 emission levels for 4W and 3W were less for EVs (less by more than 47% and 28% respectively), for buses it increased by more than 76%. Similar observations were echoed by Sharma and Chandel (2020). Figure 5.16 shows that the CO emissions for ICE vehicles in all the segments are higher as compared to EVs. However, in case of NO_X emissions (Figure 5.17), EVs in 3W segment showed higher emissions as compared to ICE vehicles. The other vehicle segments reported lesser emissions for EVs as compared to ICE vehicles. This is however contradictory to the findings of Sharma and Chandel, (2020) where NO_X emissions for e4W were found to be higher than their ICE counterparts. This may be attributed to the difference in the values of equivalent passenger load that has been used to calculate emissions per passenger-km.

Considering the emission scenario of EVs, it can be said that these emissions will decrease as the contribution of renewable energy sources increase in the energy mix. Government of India has already planned to double the installed capacity for renewable energy sources by 2030 (Sharma and Chandel, 2020). Till renewable sources become a majority contributor in energy mix, these emissions at plant level needs to be accounted for as far as EV implementation is concerned.

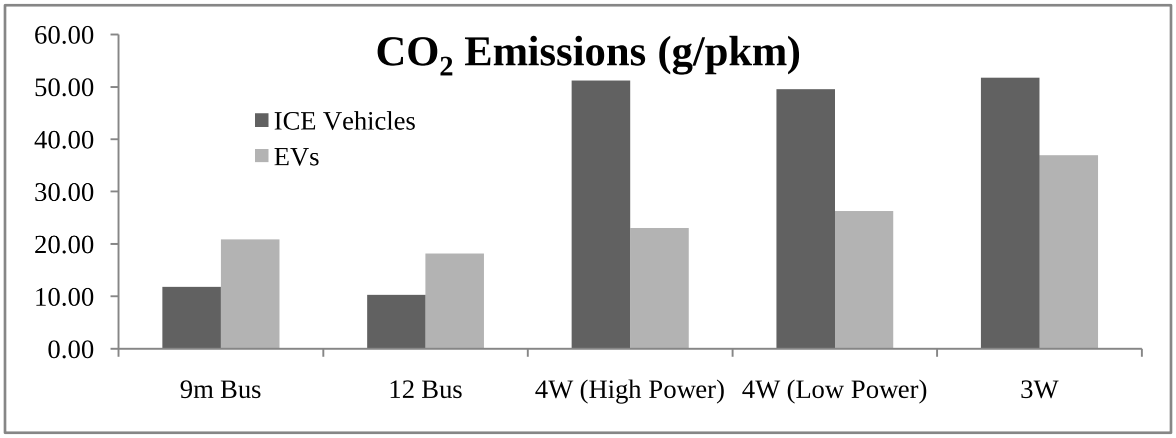


Figure 5.15: CO_2 Emissions comparison

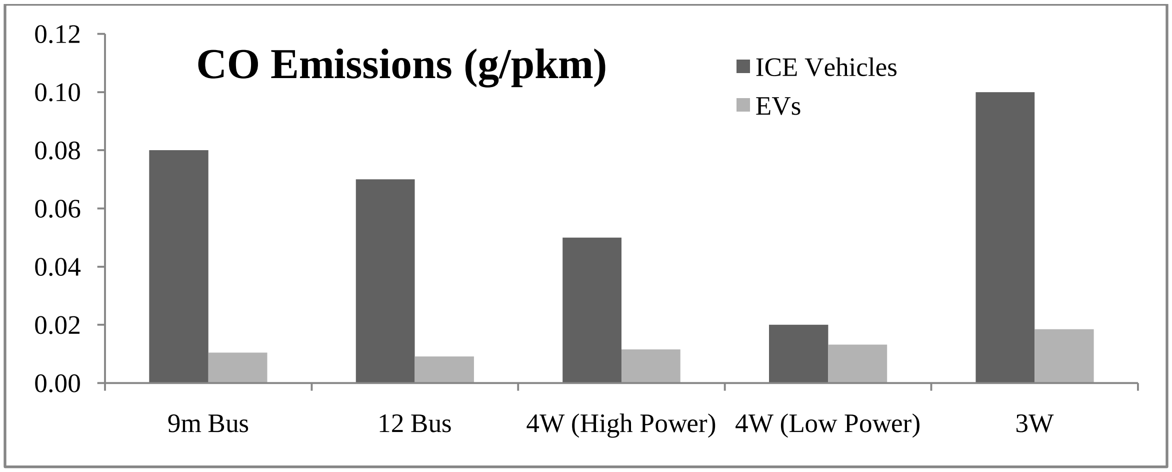


Figure 5.16: CO Emissions comparison

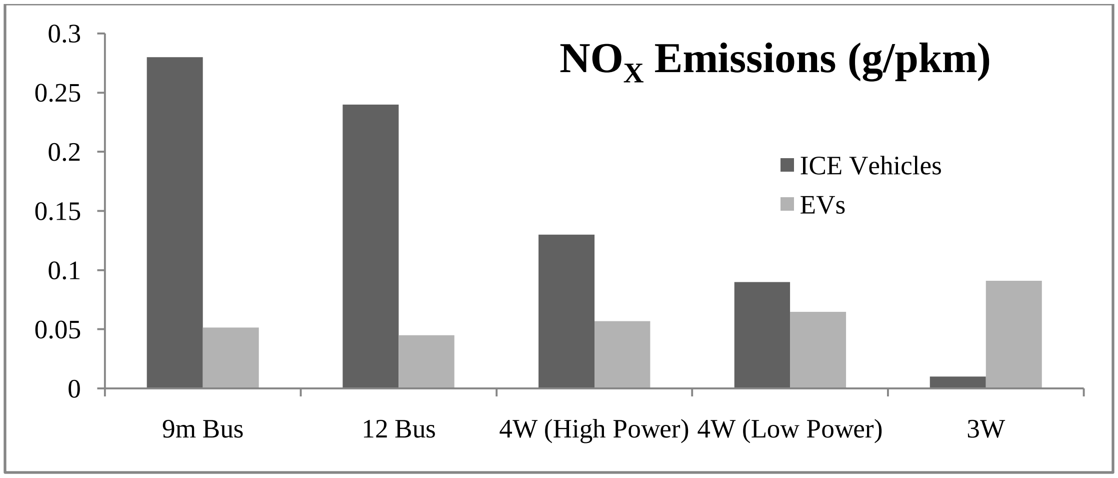


Figure 5.17: NO_X Emissions comparison

5.3.1.4 Possibilities of Private Bus Operators Adopting Electric Buses in Passenger Transport

FAME was initiated by Government of India under the National Electric Mobility Mission Plan (NEMMP) to reduce the use of fossil fuel powered vehicles. However, it has to be understood that as long as EVs represent only a small portion of the total vehicle fleet, the tailpipe emissions of ICE vehicles in congested roads and slow moving traffic will nullify the benefits of the EVs. A congestion free road with smooth moving traffic can be achieved only when commuters choose mass transit over personalized vehicles. A more effective approach is for the commuters to switch to electric mode of mass transit such as electric buses (eBuses). In order to achieve this, there should be adequate availability of eBus services that can enable commuters to reach their destination within a reasonable time. Government has taken a sensible approach in introducing eBuses to address this scenario. Around 220 eBuses under FAME I are operating in eight cities all over the country and 2450 eBuses have been procured as of November 2020 out of 5595 buses allotted under FAME II (EBus Procurement Commentary). In India, where buses account for 75% of public transport trips, buses operated by SRTUs represent only 7.3% of the total number (EBus Procurement Commentary, Road Transport Year Book, 2017-18 & 2018-19). Clearly the present numbers of buses are insufficient considering the transportation demands. The city of Kolkata, having a population of around 14.9 million people, is no exception (worldpopulationreview.com). Presently 7369 buses are plying the city streets out of which 5583 buses are privately operated and 1786 buses are government operated (https://timesofindia.indiatimes.com). For the government to achieve its vehicle fleet electrification target, the participation of private bus operators is of utmost importance. In order to understand whether the private bus operators will be optimistic to operate eBuses, it is necessary to have an outlook of the economic conditions under which they are operating presently. For this purpose, a survey was conducted and individuals associated with this occupation such as bus owners, drivers, conductors, starters, and mechanics were interviewed. Cost analysis for this particular study was done between Non AC diesel bus and AC eBus since the private operators primarily operate only Non AC diesel buses. Cost analysis was done based on capital expenditure (capex) and operational expenditure (opex) (Figure 5.18). Cost of purchasing the bus was considered under capex whereas the other recurring expenses were considered under the opex. Yearly or quarterly expenses such as certificate of fitness (CF) charges, road taxes, and vehicle insurance charges were converted into monthly expenses and considered under opex. Maintenance charges for eBuses were assumed to be 5% of the energy cost.

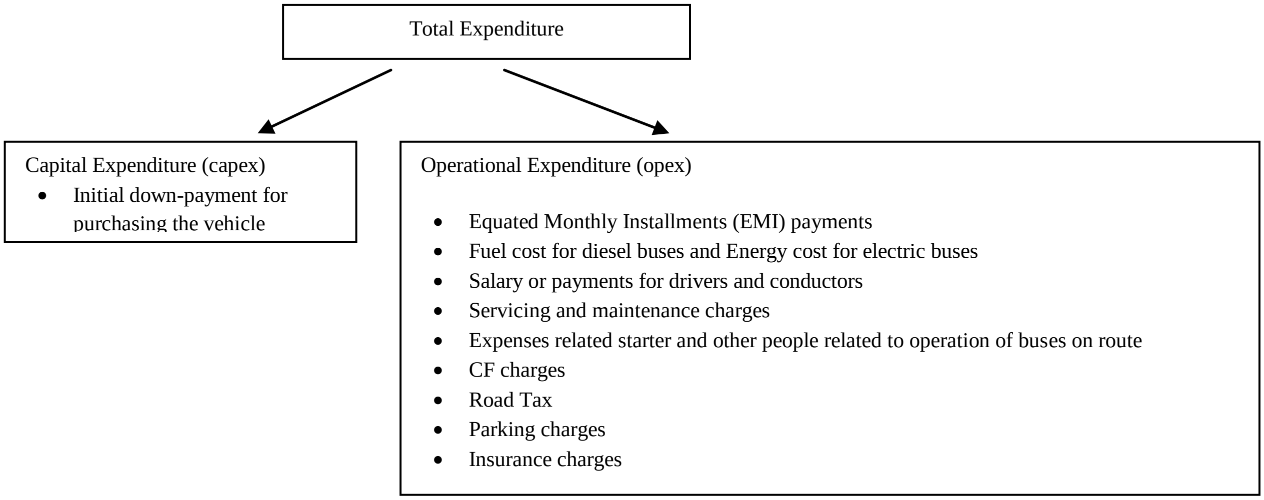


Figure 5.18: Classification of total expenditure

For calculating the EMI payments, the initial down payment was assumed to be 10% of the total cost. The rate of interest for the loan amount was assumed to be 9.5%, compounded annually. Loan period for the calculations were assumed to be 5, 10 and 15 years. The assumptions were based on the interactions with bus owners and banking officials during the primary survey. The monthly payments were calculated using an EMI calculator (tata-buses-emi-calculator). The monthly income from ticket sale and other expenses, excluding maintenance cost and energy cost has been assumed to be same for both diesel buses and AC eBuses. Benefit Expenditure Ratio (*BER*) may be defined as a ranking system and can be expressed by the ratio of net monthly profit to the sum of expenses. *BER* for different bus models has been calculated as shown in equation 5.11:

$$BER = \frac{Y_{ts}}{\sum_{1}^{x} Y_x} - 1 \tag{5.11}$$

where, Y_{ts} = Earnings from the ticket sale

Y_x = Expenses of type x

x = number of opex

Based on information obtained from the survey, it was inferred that operating conventional Non AC private buses is not as profitable as it used to be. The main reason behind this is that although the operating cost has increased over last few years, the income generated has not increased in the same proportion. For example, the last hike in fare price was in June 2018 when the price of diesel was ₹ 71.13 per liter (er.indianrailways.gov.in, petrol-diesel-price-today). Presently the diesel price has increased to ₹ 89.78 per liter (mypetrolprice.com). However, officially, the fare for private buses has not been increased. Unofficially, the fares collected by the bus operators vary between ₹ 10 to ₹ 25 based on distance travelled. Apart from this, cost of spare parts, maintenance charges, fitness certificate charges, road taxes, insurance charges, etc. have also increased. Subsequently the profit margins of operating these vehicles have reduced. In order to motivate private bus owners to operate eBuses, among other factors, the most powerful incentive is profit margin. To find out the probable profit margins, a cost analysis of operating AC eBus as compared to conventional diesel bus was done as shown in Table 5.15. The values in the table other than purchasing cost, earnings from ticket sale, and *BER*, are expressed as percentage of purchasing cost. Initial down payment for the buses at the rate of 10% of total cost price was estimated to be ₹ 300000, ₹ 750000 and ₹ 880000 for Non AC ICE bus, 9m AC eBus and 12m AC eBus respectively.

It can be observed that at present cost price, operating an eBus having a loan period of 5 years is a loss making proposition mainly due to high EMI payments. For a loan period of 7 years, operating a 9m eBus is almost as profitable as operating a ICE bus whereas operating a 12m eBus is almost a no loss no gain scenario due to its minor profit margins. For a loan period of 10 years, the profit margins of operating an eBus is much higher as compared to the current profit margins of an ICE bus. Under present conditions the most profitable option for private operators is to operate a 9m eBus for a loan period of 10 years. It has to be noted that a 12m eBus can accommodate more passengers as compared to a 9m eBus. Also the seating capacity of a 12m eBus is 40 passengers whereas for a 9m eBus it is 31 passengers (tata-urban-9-12m-ac-electric-bus, tata-ultra-9-9m-ac-electric-bus). The increased number of passengers transported will lead to increased ticket sale which might have an impact on the profit margins.

Table 5.15: Cost Analysis for Operation of Diesel Bus and Electric Bus in Kolkata

Financial Heads	**Non-AC ICE Bus**	**Loan Period**					
		(5 yrs)		**(7 yrs)**		**(10 yrs)**	
		AC eBus (9m)	**AC eBus (12m)**	**AC eBus (9m)**	**AC eBus (12m)**	**AC eBus (9m)**	**AC eBus (12m)**
Purchasing Cost of Bus (₹) - C	3000000*	7500000	8800000	7500000	8800000	7500000	8800000
Initial down payment (10% of C)	300000	750000	880000	750000	880000	750000	880000
Earnings from Ticket Sale (₹) – Y_{ts}	210000	210000	210000	210000	210000	210000	210000
EMI @ 9.5% with 10% down payment (% of C) – Y_1	1.16	1.90	1.89	1.48	1.47	1.17	1.16
Diesel Cost / Energy Cost (% of C) – Y_2	3.50	0.41	0.35	0.41	0.35	0.41	0.35
Monthly Salary for Driver (% of C) – Y_3	0.65	0.26	0.22	0.26	0.22	0.26	0.22
Monthly Salary for Conductor (% of C) – Y_4	0.35	0.14	0.12	0.14	0.12	0.14	0.12
Monthly Servicing and Maintenance Cost (5% of Energy Cost in case of EV) (% of C) – Y_5	0.17	0.02	0.02	0.02	0.02	0.02	0.02
Starter and other Expenses (% of C)	0.23	0.09	0.08	0.09	0.08	0.09	0.08
CF Charge (% of C)	0.14	0.06	0.05	0.06	0.05	0.06	0.05
Road Tax (% of C)	0.02	0.01	0.01	0.01	0.01	0.01	0.01
Parking Charges (% of C)	0.0100	0.0040	0.0034	0.0040	0.0034	0.0040	0.0034
Insurance Charges (% of C)	0.13	0.05	0.05	0.05	0.05	0.05	0.05
Benefit Expenditure Ratio	0.10	-0.05	-0.14	0.11	0.01	0.26	0.16

Operating EVs involve high capex due to its high initial purchase cost. Now in case of government operated eBuses, there are subsidies and funding from different funding projects.Buses procured under FAME I were under the capex model where West Bengal Transport Corporation (WBTC) were in charge of both operation and maintenance and received subsidy under FAME I. Presently the cost of an eBus varies approximately between ₹ 75 lakhs to ₹ 88 lakhs which is expected to be ₹ 140 lakhs in future (wbtc.co.in, iea.blob.core.windows.net). In case the prices of eBuses increase in future, bearing the initial cost might be an issue for the private operators. Also this will have an impact on the EMI payments and subsequently on the profit margin. Again, any kind of subsidy provided would become a burden on the government which would normally reflect in one way or the other on the budgetary decisions for the citizens. Public private partnership (PPP) model can be implemented with the involvement of private operators in the electrification drive to alleviate the burden of high capital cost. It will be the responsibility of the operators to only operate and maintain the buses against a fixed monthly incentive. In this way the burden of EMI payments may be reduced. Presently the drivers and conductors in the privatized bus sector are incentivized on a commission basis which varies approximately from 24% to 29% of the total income generated from ticket sale. Thus salary system may be introduced to obtain a structured outlook of incentive models. Under FAME II scheme, eBuses in Kolkata are procured under Gross Cost Contract (GCC) model where the operator will be paid fixed rate and will have to provide for both operation and maintenance of the eBuses, depots and terminus (iea.blob.core.windows.net). Similar operative model applies for private sectors agencies too; however the leniency and financial aspects would change considering the present private bus sector in Kolkata. Soft loan schemes that apply for individual private owners may be introduced to reduce the opex margin resulting in increase in *BER*.

Charging of eBuses currently operating in Kolkata is executed at government bus depots only. However with the increase in the number of eBuses, availability of charging facility will prove to be an issue due to absence of proper infrastructure. Government has already started developing charging infrastructure for EVs. However more number of proper charging infrastructures that are easily accessible to private bus operators is needed at bus stands throughout the city. For a starter, government can allow the private bus operators to access the charging infrastructure available at the SRTU bus depots. Certain changes in policies, revising of ticket pricing, enhancement of payments and incentives can surely encourage the active participation of private bus operators.

5.3.2 Study on Impact of Vehicle Loading on Specific Energy Consumption and Vehicle Mileage

Weight of vehicles has its own impact on energy consumption. Carlson et al. (2013) studied the impact of vehicle mass on energy consumption and observed that a 10% change in mass changed the energy consumption by 2.4% to 4.1%. Liu et al (2019) observed positive correlation between vehicle mass and energy consumption for both ICE bus and eBus. Not much literature is available in Indian context. Therefore a study was conducted to study the variation in fuel consumption with load in private cars. Permission to conduct experiments on vehicles of mass transit could not be obtained and hence private vehicles were chosen for the study. Three test vehicles manufactured by Suzuki were considered for the current research: ZEN Estilo VXi, Alto 800 Lxi and Swift Dzire Vxi. Table 5.16 illustrates the characteristic details of the test vehicles utilized during the real-time traffic data acquisition. Five individuals were selected as load for the cars. The mean weight for the individuals was 86 kg with a standard deviation of 8.75 kg.

Table 5.16: Test vehicle specifications

Specifications	Zen Estilo	Alto 800	Swift Dzire
Engine	1061 cc	796 cc	1298 cc
Number of Cylinder	4	3	4
Valves per Cylinder	4	4	4
Transmission Type	Manual	Manual	Manual
Gear Box	5 Speed	5 Speed	5 Speed
Drive Type	FWD	FWD	FWD
Fuel type	Petrol	Petrol	Petrol
Acceleration (0 – 100 kmph)	16.26 s	17.7 s	11.6 s
Seating Capacity	5	5	5
Length	3495 mm	3495 mm	4160 mm
Width	1495 mm	1475 mm	1690 mm
Height	1595 mm	1460 mm	1530 mm
Wheelbase	2360 mm	2360 mm	2390 mm
Vehicle Weight	855 kg	705 kg	1070 kg

On-road data were collected at real-time traffic conditions using same data logging device as mentioned in earlier chapter, with variations in routes. The route selection was determined based on longest possible ‘cross-way’ city traffic in order to exploit most of the variations in traffic behavior among the other city-routes. The real-time study was extended over a total distance of 3796.32 km that includes GPS real-time data acquisition and load variations. The routes selected for conducting this survey have been shown in Table 5.17 and illustrated in Figure 5.19.

Table 5.17: Study routes and corresponding distances

Sl. No.	Route	Distance (km)
1.	Dhakuria – Salt Lake Karunamoyee	15.70
2.	Salt Lake Karunamoyee – Chinar Park	13.65
3.	Chinar Park – TCS Gitanjali Park	10.56
4.	TCS Gitanjali Park – Iris Hospital	23.00
5.	Iris Hospital – Baghbari	10.42
6.	Baghbari – TCS Gitanjali Park	28.98

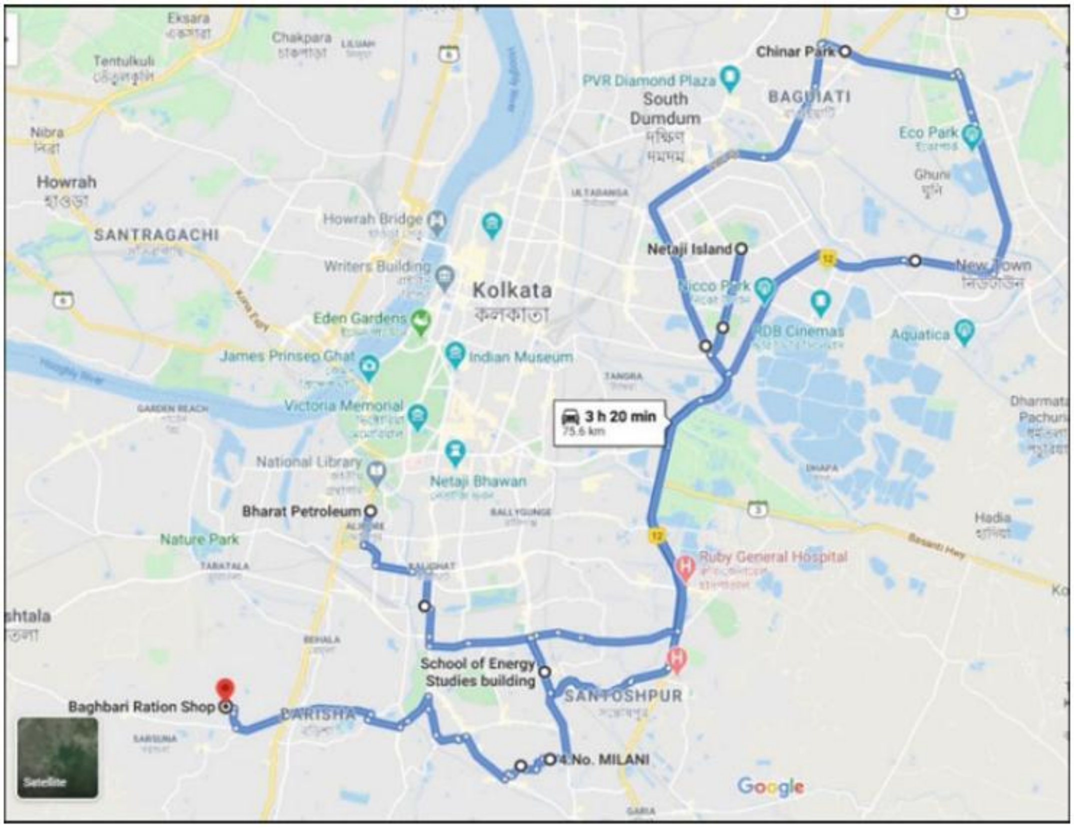


Figure 5.19: Survey Route map (*Courtesy* Google Map)

Calorific value for gasoline was considered as 45 MJ/kg, taken as the average of a likely calorific value of 44–46 MJ/kg (worldnuclear.org). The fuel densities as available for the various fuel stations also varied and were tabulated as shown in Table 5.18.

Table 5.18: Variation of fuel density

Fuel station	Gasoline Density (kg/m^3)
Uma Service Station, Gariahat Rd, IOCL	746.5
Daga Auto Service Pvt. Ltd, Slat-Lake, HP	746.0
Uma Service Station, Gariahat Rd, IOCL	754.1
Newtown Filling Stn, Atghora, IOCL	751.6
Uma Service Station, Gariahat Rd, IOCL	753.8
Average	750.4

In Tables 5.19 and 5.20, the obtained results for the specific energy consumptions and mileage of the test vehicles has been tabulated, respectively. The following Figure 5.20 shows the specific energy consumption variation with that of vehicle load. Corresponding evaluation of the vehicle mileage reveals somewhat different picture from the per capita consumption scenario.

Table 5.19: Specific energy consumption for test vehicles

Passenger Load	Specific Energy Consumption (MJ/pkm)		
	Zen Estilo	Alto 800	Swift Dzire
1	3.184	2.180	3.412
2	1.276	0.817	1.969
3	0.708	0.773	1.402
4	0.732	0.902	0.662
5	0.488	0.507	0.533

Table 5.20: Mileage for test vehicles

Passenger Load	Mileage (km/l)		
	Zen Estilo	Alto 800	Swift Dzire
1	10.62	15.48	9.89
2	13.45	20.65	8.57
3	15.88	14.54	8.02
4	12.29	9.35	12.73
5	14.78	13.29	12.66

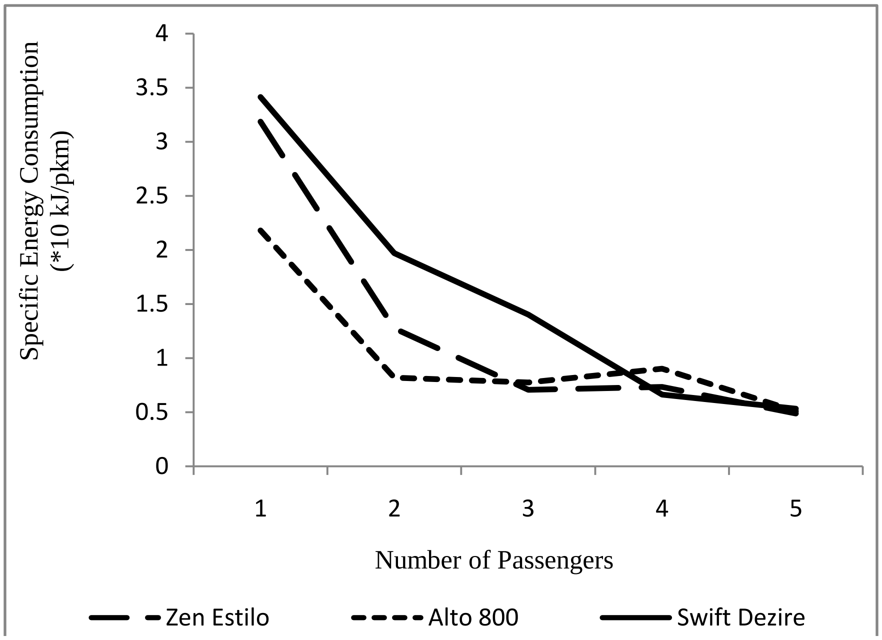


Figure 5.20: Variations in specific energy consumption

As shown in Figure 5.21, the optimum mileage for the test vehicles' parameters and the traffic conditions was obtained at different occupancy level than that of the specific energy consumption.

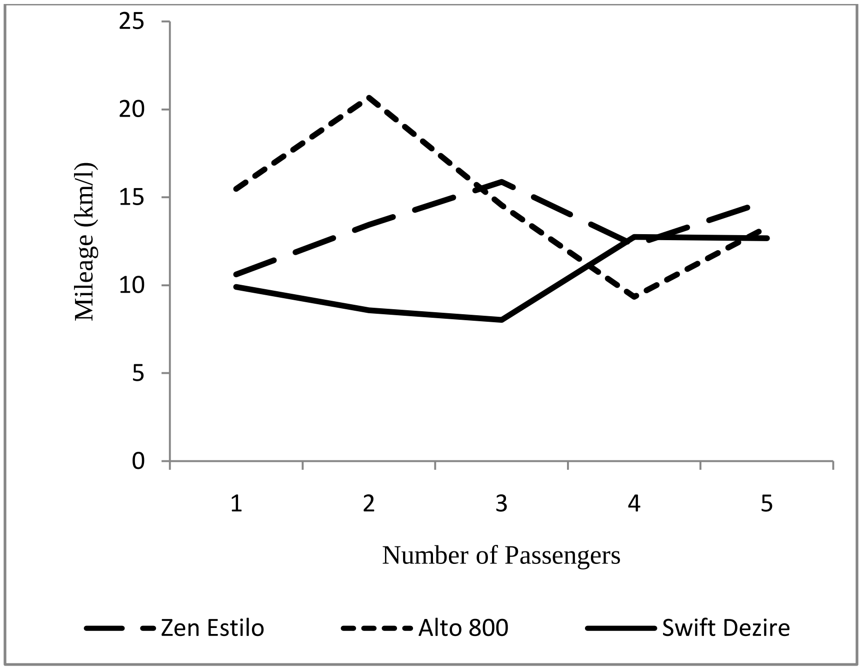


Figure 5.21: Variations in vehicle mileage

Such outcome showed that the traffic conditions as well as vehicle loading had a direct influence on vehicle performance, but the optimum condition may be reached depending upon the vehicle use basis. From this finding it can be delineated that, to obtain the ideal outcome from the vehicles, the vehicle type should be selected accordingly so as to match the prefixed load or passenger number, resulting in low energy consumption per passenger-km travelled, and also decreasing the resultant pollution.

In case of all the subject vehicles, the optimum performance occurred at passenger occupancy of 5 and the highest energy consumption was for a single passenger. Thus the effect of optimum loading of the vehicle may be deciphered from this data set. But the lowest energy consumption was for Zen Estilo model at 0.489 MJ/pkm. On the contrary the highest road performance or mileage varied as per the vehicle models, i.e. engine specifications. For Alto 800, the optimum mileage was obtained at 2 passengers, for Zen Estilo model it occurred at 3 and for Swift Dzire model; mileage was maximum for 4 passengers. Hence it was concluded from this study that vehicle loading impacted energy consumption and that car pooling can be used to conserve energy.

5.3.3 Efficient utilization of vehicles:

In day to day life, periodic maintenance of vehicles or simple changes in vehicle operational methods can contribute to energy conservation. For example, switching off the vehicle engine when not in use or at traffic signal halts, or smooth driving of vehicles at constant speed without sudden changes in speed, etc. Some of these methods have been discussed in the following sections.

5.3.3.1 Vehicle Maintenance

In order to function properly at an optimal condition, every vehicle needs periodic maintenance after a certain amount of distance travelled or a fixed amount of time, as directed by the vehicle manufacturer. Ang and Deng, (1990) studied the effects of maintenance on fuel efficiency of public buses and observed significant improvement in fuel efficiency after each major vehicle maintenance. Sikarwar and Baghel, (2017) studied the impact of poor maintenance of vehicles on fuel consumption and observed that change in air-fuel ratio from the manufacturer’s air fuel ratio could increase the fuel consumption by 10.16% to 22.14% in case of city roads and 7.46%

to 19.05% in case of highway roads. None of the commercial vehicles surveyed under the scope of this research work practice the habit of timely maintenance. For these vehicles, maintenance is only on a “need to” basis. Until and unless the issue is severe enough to stop the vehicle operation, it is tried to be overlooked. The efficiency of a vehicle without maintenance is bound to deteriorate faster over time as compared to a vehicle with proper scheduled maintenance which in turn will lead to higher energy consumption. Even tyre pressure has its impact on fuel consumption. Varghese, (2013) studied the influence of tyre pressure on fuel consumption using a mathematical model in Matlab/Simulink interface and observed that increasing the tyre pressure from 0.2 MPa to 0.3 MPa resulted in reduction of fuel consumption by up to 5%. Szczucka-Lasota et al. (2019) studied the influence of tyre pressure on fuel consumption in trucks and observed that with the increase in pressure by 0.1 MPa, fuel consumption decreased by an average of 5.15 l/100 km. Hence proper maintenance of a vehicle is a way to ensure energy conservation.

5.3.3.2 Driving Habits

Different drivers have different driving styles. Some prefer driving smoothly while some are comparatively more aggressive. Sometimes the driving pattern is influenced by road and traffic conditions. For example, a congested driving scenario influences a driving pattern characterized by sudden accelerations and decelerations and frequent stoppages with low average speed. On the other hand a free flowing or highway driving is characterized by smooth accelerations and decelerations and high average speed. Tzirakis et al. (2007) studied the impacts of driving style on fuel consumption and observed that aggressive driving resulted in increased fuel consumption by 78.5% to 137.3% in case of petrol vehicles and 116.3% to 128.3% in case of diesel vehicles. Berry I.M. (2010) observed that it would be beneficial for aggressive drivers to focus on reducing accelerations and for less aggressive drivers to focus on driving at lower speeds in case of highway scenario. It was also observed that maximum fuel savings could be obtained if aggressive drivers, driving moderate performance vehicles, could drive with lower accelerations. Miotti et al. (2021) attempted at quantifying the impact of changes in driving style on fuel consumption of light duty vehicles and observed that early deceleration and gradual acceleration contributed to fuel savings. It was also observed that improvements in driving style resulted in an average fuel savings of 6% per trip. Heijne et al. (2017) observed that for a conventional technology vehicle, braking, gear shifting and velocity has 10% or higher impact on fuel consumption. Clearly, it is evident that driving a vehicle properly at steady speed without sudden changes in acceleration and deceleration can help in energy conservation.

Ghose et al., (2004) mentioned that emissions from motor vehicles are minimized if they can operate at steady-state speed of 50 km/h. Errampalli et al., (2015) observed that optimum speed for petrol driven small cars, diesel driven big cars and two wheelers are 58 km/h, 62 km/h and 60 km/h respectively. However, the DC data obtained from this study showed that 25.16% to 31.29% of the travel time was spent in idling, 51.48% to 59.58% of time was spent in accelerating or decelerating for buses and 4W. Average speed for the vehicles varied between 12.79 km/h to 19.40 km/h. This kind of driving scenario can be considered under congested driving conditions. According to Errampalli M et al. (2015), congestion was responsible for 41% extra fuel consumption and 48% extra travel time spent. Energy conservation under such congested conditions is very difficult and can be achieved only if drivers are skilled and patient enough to maintain smooth accelerations or decelerations and steady speeds. A better alternative is to maintain roads and control traffic properly so as to facilitate congestion free and free flowing traffic conditions.

5.3.3.3 Shift to mass transit and car pooling

DC data showed that the driving conditions of the surveyed location resembled a congested traffic scenario characterized by high idling time, frequent acceleration and deceleration events and low average speed. One of the main reasons behind this is increase in vehicle population over time. Looking back at the history of motorized transport, there was a time when mass transit vehicles were the only vehicles available and numbers of personalized vehicle was negligible. However, as time passed, with regional, social and economic development, and increase in population, the number of vehicles became insufficient to cater to the needs of the commuters. For example, considering population of Kolkata to be 15.3 million (worldpopulationreview.com) in 2023 and required number of buses per 1000 population to be 1.2 (UrbanBusToolkit), the required number of buses in the city turns out to be 18360. However, the numbers of buses available are merely 7369 (timesofindia.indiatimes.com). This, along with increase in purchasing power of people, has resulted in a major shift towards usage of personalized mode of transport. As a result the on-road vehicle density has increased which in turn has contributed to increased congestion. Shifting to mass transit can prove to be an efficient method of solving this issue. As it has been already mentioned earlier, specific energy consumption for an ICE bus and a 4W are 0.08 kWh/pkm and 0.28 kWh/pkm respectively. Clearly this is a reduction of 71.43% as a person switch from a 4W to a bus. As more and more people shift to using buses instead of personal vehicles, reduction in the number of 4W plying the streets will reduce vehicle density and hence contribute to reduce the effects of congestion.

"Car pooling", the concept of sharing of cars while commuting to office or schools, has become popular and can prove to be efficient in conserving energy. Previously, people having personal cars, used to prefer to ride alone to office. However, the continuous increase in price of fuel kept on adding an extra economic burden on the pockets of vehicle owners. In order to reduce this burden, groups of friends or people knowing each other, commuting in the same route or to the same destination, started sharing their vehicles as well as the fuel expenses. This way, on one hand the fuel expenses for the vehicle owner was reduced and on the other hand the commuting needs for the commuters sharing the vehicle was met. Hence both parties were benefited. In order to extend the benefits of this concept from within small groups of friends to more and more people, Smartphone applications such as sRide has come into existence. These kinds of apps connect vehicle owners who want to share their rides with commuters looking for a ride.

A study conducted on variation in fuel consumption with vehicle loading (discussed in later section) revealed that the mileage of a hatchback (>1000cc) improved by 39.21% and for sedan (>1000cc) improved by 28% when vehicle loading changed from D (driver) to D+4 (driver + 4 passenger). Best mileage for hatchback (<1000cc), hatchback (>1000cc) and sedan (>1000cc) was obtained for occupancy rate of 2, 3 and 4 passengers respectively. Also per-capita energy consumption improved by 76.71% for hatchback (<1000cc), 84.66% for hatchback (>1000cc), and 84.37% for sedan (>1000cc) when vehicle loading changed from D to D+4. Hence the concept of car pooling can be used to conserve energy. Whether this concept can contribute to reduce on-road traffic congestion needs to be studied further.

5.3.3.4 Fuel Wastage

Wastage of fuel due to unnecessarily keeping the vehicle engine running is an issue which is highly overlooked. This phenomenon has been observed mainly in case of commercial vehicles, especially buses. Whenever these vehicles are stuck at a traffic jam or at traffic signals, the engines of these vehicles keep on running, however long these halts may be. In order to estimate the amount of fuel wastage, a study was conducted at bus stands in Kolkata and it was observed that all AC buses kept its engines as well as AC systems running for the entire duration while waiting for its next trip, irrespective of availability of passengers. The average wait time in between two consecutive half trips for a bus was observed to be 20 minutes. Considering idling fuel consumption of 150 ml/10 minutes (Saxena et al., 2014), and 3.5 trips per day, the fuel wastage estimated to 1.8 liters per bus per day. Considering fuel consumption of 59.73 liters per day for a 9m AC ICE bus and 120 liters per day for a 12m AC ICE bus, the daily fuel wastage per bus turns out to be 3.01% and 1.5% respectively. From the point of view of energy conservation, this kind of unnecessary fuel wastage is undesirable and can be avoided easily.

5.3.4 Infrastructure development and Government policies

Infrastructure is an integral part of transportation system and plays an important role in the development of the same. Government policies can be considered to be tools which can be used to formulate various development plans and bring them into reality. Over the years government has developed various programmes to build and upgrade urban transport infrastructure focusing especially on public transport. National Urban Transport Policy (2006), Jawaharlal Nehru National Urban Renewal Mission, 100 Smart Cities Mission, and Atal Mission for Rejuvenation of Urban Transport are some of these programmes (Indian Energy Outlook 2021). Implementation of odd-even policies in Delhi resulted in reduction of PM concentration by up to 70% (Kuppili et al. 2021). In case of Kolkata, numerous flyover projects and metro rail route extensions have been sanctioned to address the road congestion scenario and ensure faster mass transit. AJC Bose Road flyover has been built to address the congestion scenario at Exide, Minto Park and Beckbagan crossings. Maa flyover has been built to address the congestion scenario at Park Circus 7 Point crossing. Existing metro rail route from Dumdum to Tollygunge has been extended from Dakshineswar to New Garia. New metro rail routes have been started from Sector V to Phoolbagan and Joka to Taratala. More routes are under construction.

Apart from these, government can look into widening the roads wherever possible. Kolkata, being a very old city, is not properly planned and has little room for modification to the existing road infrastructure. Moreover in many places foot paths meant for pedestrians have been blocked by temporary shops built by hawkers. This has forced the pedestrians to use roads thereby decreasing the effective road width contributing to congestion. However government interventions can solve this problem. Enforcing stricter policies to prevent hawkers from utilizing foot paths and relocating these shops to a favorable location can contribute to improving the congestion scenario. Again reckless driving, unnecessary overtaking, or intentional slow driving can contribute to congestion and traffic jams. Enforcing harsh penalties can force these offenders to improve driving habits and contribute to smooth driving and congestion free roads. Also getting a driving license is easy in India and does not require much skill as compared to some of the other countries. Increasing the difficulty level of the driving tests can ensure that only skilled drivers get to drive vehicles on road. This in turn can also contribute to improving on-road congestion scenario. Development of DC and data obtained from them can be utilized as guidelines for policy formation. For example, DC data showed that average speed of an ICE bus was 12.79 km/h and for a 4W it was 19.40 km/h whereas Errampalli et al., (2015) showed that optimum speed for cars and 2W varied between 58 km/h and 62 km/h. Hence policies must be aimed at improving vehicle speeds. Again DC data showed that buses and 4W spend maximum time in acceleration or deceleration and then in idling. Hence policy formation should be aimed at providing congestion free roads that can enable smooth driving and minimum idling. Also, government has to allocate more funds to dedicated research in this field, especially to development of regional DCs, if the energy conservation and pollution has to be addressed properly.

5.4 Conclusion:

It was observed from this study that in most cases, for most of the pollutants, emissions per passenger-km was less for ICE buses as compared to 4W and 3W. The case of NO_X emissions was exceptional where ICE buses emitted more pollution per passenger-km as compared to the other vehicles. It was also observed that within 4W segment, emissions per passenger-km from Ambassador Taxi were much more as compared to the others, despite having same equivalent passenger load. Main reason behind this can be the vehicle age. All Ambassador Taxis plying the city streets are very old and most of these vehicles are nearing the end of their on-road lifetime. Other 4W such as Ola/Uber cabs or Tata Magic are more recent vehicles and hence engine conditions for these vehicles are probably much better as compared to Ambassador Taxis.

Mahindra Bolero has an equivalent passenger load of 5 and hence was not compared with these vehicles. In 3W segment, diesel auto rickshaws emitted more pollution per passenger-km as compared to LPG auto rickshaws in most cases. However in case of CO_2 emissions, pollution per passenger-km emitted by these two types of vehicles was comparable. It was also observed that CH_4 emissions per passenger-km for diesel auto rickshaws and SO_2 emissions per passenger-km for Ambassador Taxi were exceptionally high as compared to the other vehicles. It was also observed that amongst all the pollutants emitted by Vano, CO_2 emission per passenger-km was maximum.

As far as scope of energy conservation is concerned, EV implementation can prove to be very useful. However emissions at power plant level for EVs need to be considered. People must shift to mass transit from personalized mode of transport to reap full benefits or else increasing number of vehicles on road may nullify the benefits of EV implementation. It was also observed that simple methods of effectively using a vehicle can contribute to conserve energy. The study showed that vehicle loading impacted energy consumption and best mileage for different 4W was obtained at different passenger occupancy. Also, data obtained from DC may be used as a guideline based on which policies can be formed to ensure energy conservation. Energy conservation in road transport sector and vehicular emissions are inter related and has an inversely proportional relationship. Higher the energy conserved, lesser is the pollution. Addressing one scenario will impact the other. It is high time that common people come together and contribute to energy conservation and emission mitigation.

Abbreviations:

BER	Benefit Expenditure Ratio
CESC	Calcutta Electric Supply Corporation
CF	Certificate of Fitness
e4Ws	Electric 4 Wheelers
e3Ws	Electric 3 Wheelers
FAME	Faster Adoption and Manufacturing of Hybrid & Electric Vehicles

GCC	Gross Cost Contract
MUV	Multi Utility Vehicle
NEMMP	National Electric Mobility Mission Plan
PPP	Public Private Partnership
SOC	Sate of Charge
SRTU	State Road Transport Undertaking
WBTC	West Bengal Transport Corporation
WHO	World Health Organization

Chapter 6

Conclusion and Future Scope of Work

6.1 Conclusion:

This particular research work was started with the aim of finding out the energy consumption pattern in passenger vehicles in road transport in selected locations of West Bengal. It was assumed that the variations in topography might have an impact on the consumption pattern for these vehicles and that the understanding of the consumption scenario might help to better understand the overall picture of transport sector. As a result, a survey was conducted.

Survey results revealed that the types of vehicles plying the streets varied with the regions. 9m and 12m Non AC buses were common to all the locations except Bakkhali, where 9m buses were absent. Intra city AC buses were seen only in Kolkata. In case of 4Ws, Ambassador Taxis and Ola/Uber cabs were common to Kolkata and Durgapur but were not found in other locations. In these regions people relied more on vehicles like Tata Magic and Mahindra Bolero for daily commute. In 3W segment, Toto was common for all the locations while auto rickshaws were found only in Kolkata and Durgapur. Unconventional vehicles like Vano that were found in different locations are used for passenger transport only in Kolkata.

Energy consumption for 9m Diesel Non AC bus was observed to be less as compared to 12m Diesel Non AC bus, for all surveyed locations. Opposite trend was observed in case of Diesel AC buses where energy consumption of 9m AC bus was higher as compared to 12m AC bus. Energy consumption for eBuses was same for both 9m and 12m buses. Specific energy consumption for 9m Diesel Non AC bus was observed to be less than 12m Diesel Non AC bus for the locations of Kolkata and Mal Bazar. A different scenario was observed in Durgapur where specific energy consumption for 9m Diesel Non AC bus exceeded the specific energy consumption of 12m Diesel Non AC bus. Specific energy consumption for 9m Diesel AC bus and eBus was observed to be higher than 12m Diesel AC bus and eBus respectively. In 3W segment, energy consumption of Diesel auto rickshaws was maximum while Toto consumed minimum energy. Specific energy consumption was maximum for LPG auto rickshaws and minimum for Toto. In 4W segment, Tata magic consumed maximum energy while Ola/Uber cabs consumed minimum energy. Specific energy consumption in this segment was maximum for Tata Magic and minimum for Mahinda Bolero. It was observed that among the diesel vehicles, vehicles bigger in size and engine capacity consumed more energy. Also presence of AC in vehicles enhanced the energy consumption. Specific energy consumption, on the other hand, depended more on equivalent passenger load and hence buses performed better in this segment as compared to other vehicles (with the exception of Vano). As far as energy consumption is considered, survey conducted in this study was able to successfully establish an energy consumption pattern among the passenger vehicles in road transport sector in selected regions of West Bengal.

However, findings of the survey were unable to shed light on on-road driving characteristics of these vehicles that had huge impacts on energy consumption and emissions. Literature review revealed that driving cycles (DCs) were a great way to represent on-road traffic scenario and estimate fuel consumption as well as emissions. Researchers have already proved the fact that DCs based on which emission standards for this country has been set, deviated from the actual scenario and established the need for regional DCs. This, along with the absence of DC that can properly represent the driving conditions of West Bengal, led to the next phase of the study that concentrated on developing DCs for buses and cars.

Data obtained from DC revealed that average speed for ICE bus, eBus and 4W in Kolkata were 12.79 km/h, 17.87 km/h and 19.40 km/h respectively and idling time for the same was 31.29%, 25.16% and 28.77% respectively. Most of the travel time was spent in acceleration, deceleration and idling mode depicting a congested driving scenario. It was observed that the driving conditions in the studied location (Kolkata) varied from other regions such as Delhi, Pune, Chennai Maharashtra, etc. that has already been studied earlier. Moreover, it established the difference in driving patterns based on vehicle type, i.e bus and 4W. Variations in the parameter values of KBDC, KEBDC and K4WDC as compared to IDC, MIDC and other available DCs established the inadequacy of the later to represent the driving conditions throughout the country and verified the necessity of region based DCs. Mileage for buses and 4Ws as estimated from DC data were 3.57km/l and 16.67 km/l respectively as compared to 3.32 km/l – 3.96 km/l for buses and 10 km/l – 14 km/l for 4Ws obtained from the survey data.

Estimation of emission per passenger-km revealed the dominance of 3Ws and 4Ws as compared to ICE buses for most of the pollutants. Amongst the 4Ws, Ambassador Taxis were found to be more polluting compared to the others. The reason behind this may be because these vehicles are probably the oldest vehicles plying the streets and are nearing the end of on-road life time. In 3W segment, diesel auto rickshaws were found to be more polluting than its peers. Emission per passenger-km of CH_4 and SO_2 were observed to be exceptionally high for diesel auto rickshaws and Ambassador Taxis respectively.

As far as scope of energy conservation is concerned, replacement of convention vehicles by EVs can prove to be rewarding. Comparative study of on-road performance between eBus and ICE bus revealed that these vehicles can be worthy alternatives. However charging these EVs from conventional electricity will lead to emissions at power plant level, and that needs to be addressed properly. Regarding the possibility of eBus adoption in Kolkata, it was observed that the most profitable scenario for private bus operators based on BER calculation is to opt for operating a 9m eBus for a loan period of 10 years. Shifting vehicle variant or reducing loan period would result in drop of profit margins thereby creating an unsustainable scenario.

Further, study on the impact of vehicle loading on energy consumption revealed that the specific energy consumption for test vehicles was least at occupancy level of 5 and maximum at occupancy level of 1. However mileage for the vehicles varied as per vehicle models.

Information obtained from this research work can be utilized by the policy makers for modeling and reshaping the transport sector to attain energy conservation and mitigate pollution. Specific energy consumption values obtained from the study can provide a guideline for vehicle manufacturers attempting at improving vehicle performance. It can aid policy makers in formulating policies regarding sequential phasing out of conventional vehicles and replacing the same with EVs. The information obtained from DC can also be utilized to develop traffic signal algorithms so that idling time can be reduced thereby improving the congestion scenario. Transport sector is huge and has lot of potential with respect to future research work. This study can provide a reference for future researchers to pursue their works.

6.2 Future scope of work:

Transport sector, especially in the zone of West Bengal, has not been explored properly and hence the potential of pursuing further research in this area is high. This study deals with passenger transport while freight transport has been left out. Researchers can try to explore this area. Within passenger transport, only intra city transport has been studied in this research work. Researchers can further look into intercity transport. Different types of vehicles from road transport attend to the commuting needs for the passengers, for example, buses, 4Ws, 3Ws and

2Ws. Due to lack of resource and time, only selected type of vehicles from these categories have been studied while 2Ws have been completely left out. Further in-depth study can be conducted in each of these segments and similar study can be extended to include other vehicles from these segments. Furthermore, there is a huge network of shuttles that cater to the daily commuting needs of office going passengers in the region of Kolkata that have not be registered properly. Interested researchers may look into this area. Along with motorized mode of transport, researchers can also explore non motorized mode of transport with respect to intermediate public transit or para transit in this region.

Lack of proper documentation has led to unavailability of data for transport sector in West Bengal. This sector is in dire need of researchers who can look into this and create reliable data inventories thereby encouraging further research in this area.

Abbreviations:

2Ws	Two Wheelers
3Ws	Three Wheelers
4Ws	Four Wheelers
AC	Air Conditioned
ICE	Internal Combustion Engine
IDC	Indian Driving Cycle
K4WDC	Kolkata Four Wheeler Driving Cycle
KBDC	Kolkata Bus Driving Cycle
KEBDC	Kolkata Electric Bus Driving Cycle
LPG	Liquefied Petroleum Gas
MIDC	Modified Indian Driving Cycle
Non AC	Non Air Conditioned

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ANNEXURE I: Survey Questionnaires

Survey on Transport of Kolkata (Bus)
Jadavpur University
School of Energy Studies

Type of Vehicle:

Year of purchase:

Public / Private:

Bus No:

Route:

Distance in km:

No of trips per day:

Carrying capacity (Seating):

Carrying capacity (Standing):

Passenger Load (Weekdays [per day]):

Passenger Load (Weekends [per day]):

Fuel Used:

Fuel consumption per day:

Fuel Cost (Rs/ltr):

Mileage (km/ltr):

Time required from starting to destination point:

Operating Time (Weekdays [per day]):

Operating Time (Weekends [per day]):

Fare Structure:

Bus model(which company), BS I, BS II,

Maintenance Schedule:

Survey on Transport of Kolkata (Taxi)
Jadavpur University
School of Energy Studies

Taxi No:

Type of vehicle:

Carrying capacity:

Passenger Load (Weekdays [per day]):

Passenger Load (Weekends [per day]):

Average freight load per passenger:

No. of trips per day:

Fuel Used:

Fuel Cost (Rs/ltr):

Mileage (km/ltr):

Average Speed:

On Load Operating Time (Weekdays [per day]):

Off Load Operating Time (Weekdays [per day]):

On Load Operating Time (Weekends [per day]):

Off Load Operating Time (Weekends [per day]):

Fare Structure:

Maintenance Schedule:

Vehicle manufacturer:

BS I, BS II, specification (if any):

Survey on Transport of Kolkata (Auto rikshaw)
Jadavpur University
School of Energy Studies

Type of Vehicle:

Route:

Distance (km):

Carrying capacity:

Fuel Used:

Fuel Cost:

Mileage (km/ltr):

Average Speed:

Operating Time (Weekdays [per day]):

No of trips (Weekdays [per day]):

Operating Time (Weekends [per day]):

No of trips (Weekends [per day]):

Fare Structure:

Maintenance Schedule:

Vehicle manufacturer:

BS I, BS II, specification(if any):

EnergyConsumptionPattern_thesis

ORIGINALITY REPORT

6%
SIMILARITY INDEX

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1	Niraj Sharma, PV Pradeep Kumar, Rajni Dhyani, Ch Ravisekhar, K. Ravinder. "Idling fuel consumption and emissions of air pollutants at selected signalized intersections in Delhi", Journal of Cleaner Production, 2018 Crossref	149 words — < 1%
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