SYNOPSIS

FOR

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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1. Introduction

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**).

2. 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 6 wheeler (6W) vehicle segment, DCs were developed for both ICE bus and electric bus (eBus). DC was also developed for the 4 wheeler (4W) vehicle segment. DC for 3 wheeler (3W) segment has already been studied by Majumdar (2020) 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 emissions per passenger-km 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 ICE counterparts. It appears that a focused approach on estimating eBus 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 per-capita emission 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.

3. Chapter 3

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.

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 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.

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

$$D_{ji} = 2 \times n \times d_i \tag{1}$$

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

$$e_{ji} = \frac{l \times c}{D_{ji}} \tag{2}$$

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

$$s_{ji} = \frac{e_{ji}}{p_{eq}} \tag{3}$$

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

$$E_v = {\sum_j e_{ji}}/{m} \tag{4}$$

where, *m* = number of vehicles surveyed.

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

$$S_v = {\sum_j s_{ji}}/{m} \tag{5}$$

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

(Figures 1-4). 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.

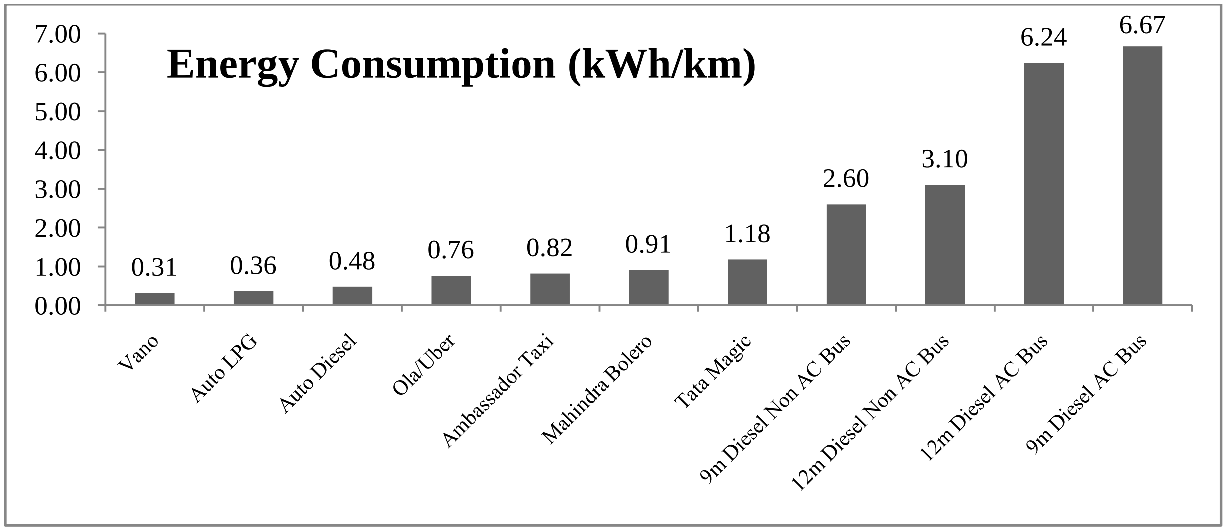

Figure 1: Energy Consumption for Non Electric Vehicles

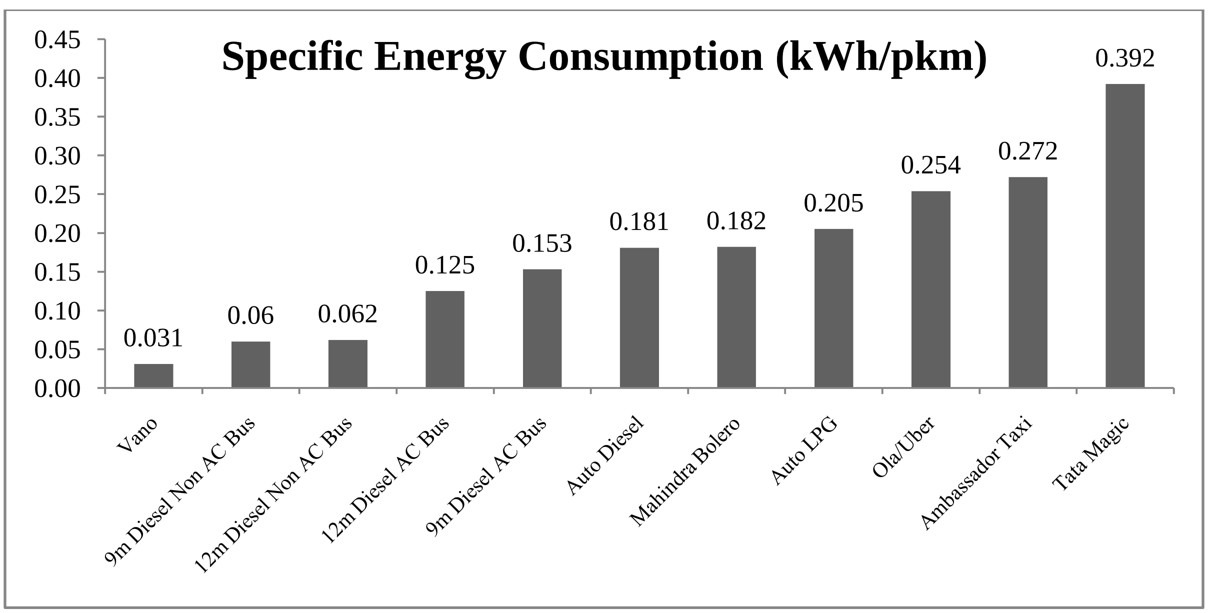

Figure 2: Specific Energy Consumption for Non Electric Vehicles

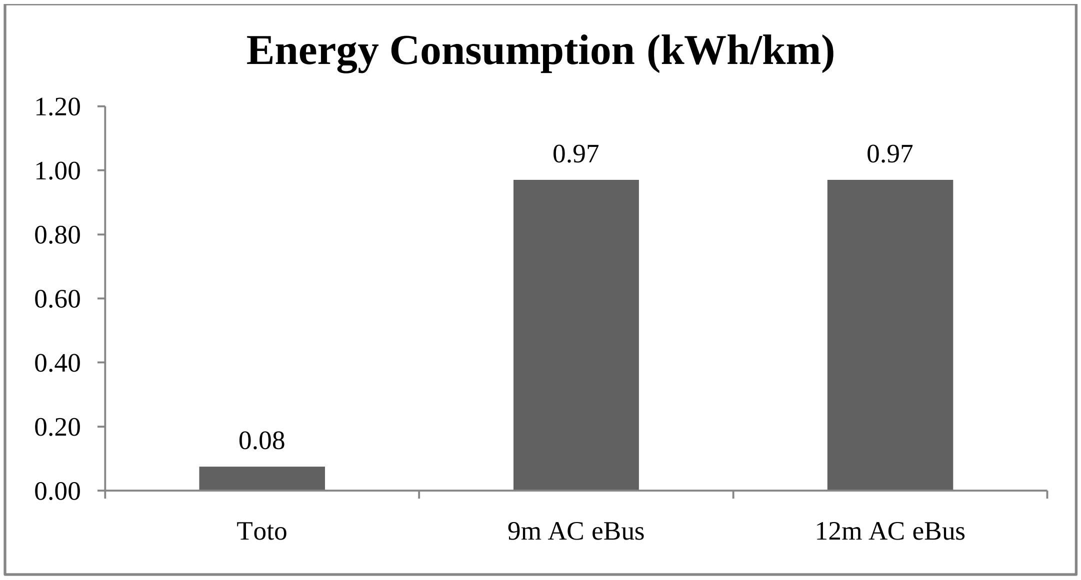

Figure 3: Energy Consumption for Electric Vehicles

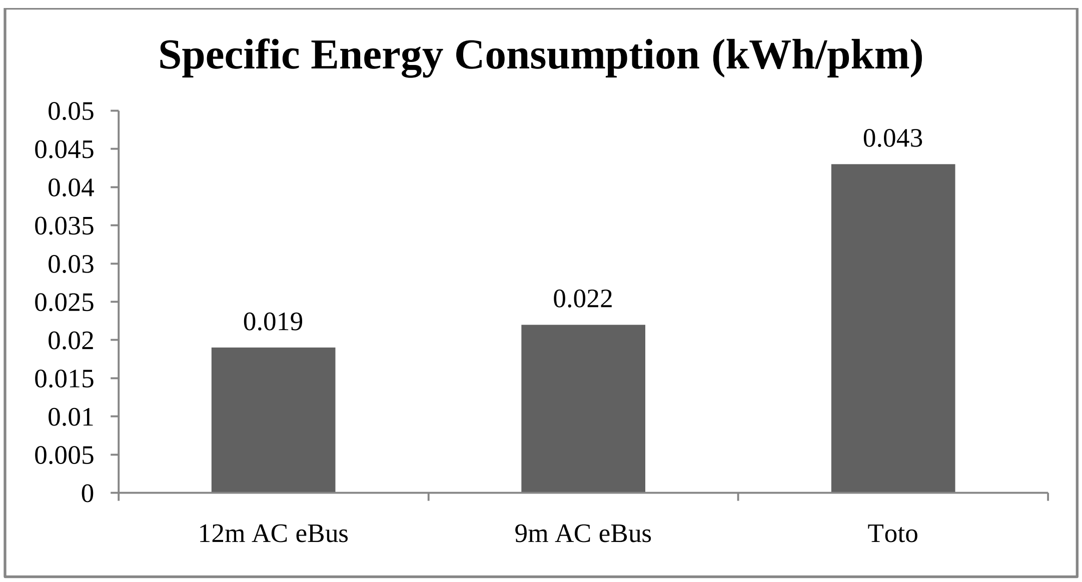

Figure 4: Specific Energy Consumption for Electric Vehicles

4. Chapter 4

Analysis of initial survey results revealed the necessity to have a closer look at the impact of various factors affecting the energy consumption scenario. Fuel consumption of a vehicle is affected by conditions like traffic speed, vehicle loading and driving behavior. 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 DC, which is conventionally represented by a speed-time or a speed-distance curve for a vehicle moving from one point to another. In this chapter the DC for bus (Figure 6), eBus (Figure 7) and 4Ws (Figure 8) for the city for Kolkata have been developed using steps shown in Figure 5and consequently the fuel consumption has been theoretically calculated from the generated DCs (Table 1).

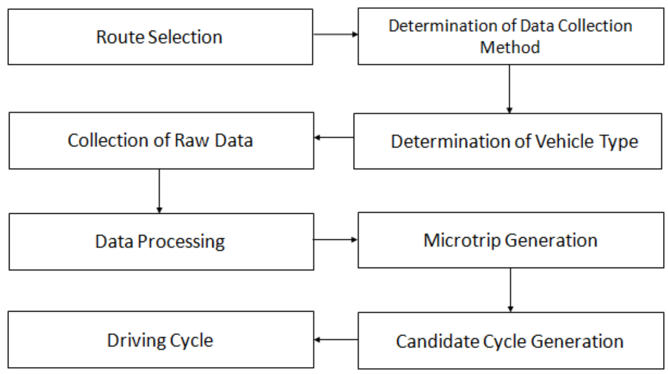

Figure 5: Steps involved in DC generation

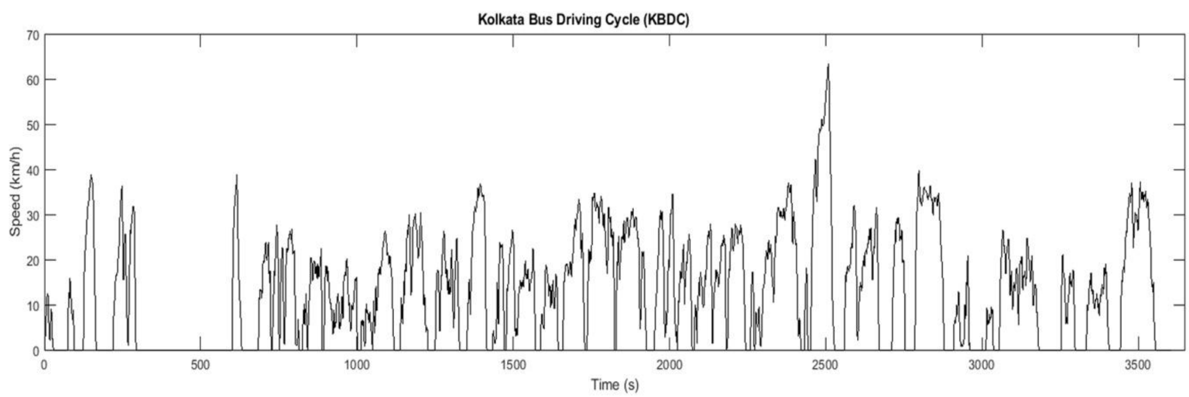

Figure 6: Kolkata ICE Bus Driving Cycle (KBDC)

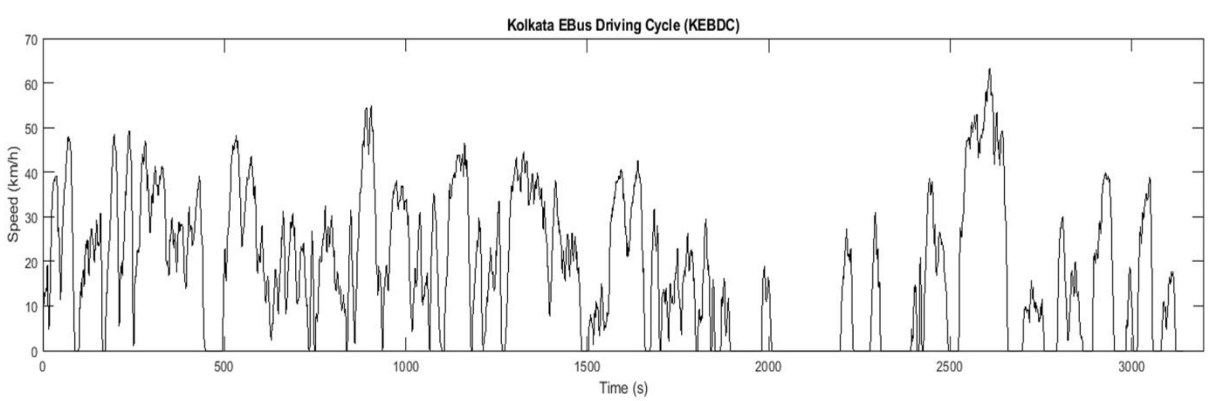

Figure 7: Kolkata eBus Driving Cycle (KEBDC)

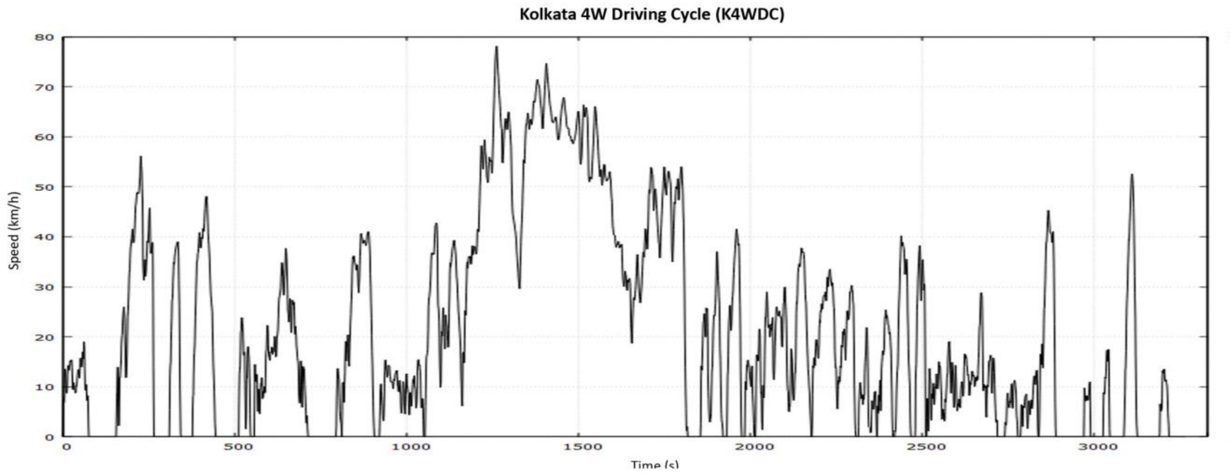

Figure 8: Kolkata 4W Driving Cycle (K4WDC)

Estimation of fuel consumption:

Fuel consumption at motion was estimated using equations 6 and 7.

$$FC_{m_{bus}} = 32.97 + \frac{3904.64}{V} + (0.0207 \times V^2) + (0.0012 \times RG) + (3.3281 \times RS) - (1.7769 \times FL) \tag{6}$$

$$FC_{m_{car}} = 21.85 + \frac{504.15}{V} + (0.004957 \times V^2) + (0.000652 \times RG) + (1.0684 \times RS) - (0.3684 \times FL) \tag{7}$$

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)

Fuel consumption at idling was estimated using equations 8-10.

$$T_{idling} = \frac{T_i \times D_{DC}}{100} \tag{8}$$

$$FC = \frac{T_{idling} \times FCR_i/_{10}}{1000} \tag{9}$$

$$FC_{idling} = \frac{FC}{S_{DC}} \tag{10}$$

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)

Overall fuel consumption was estimated using equation 11.

$$FC_{DC} = FC_m + FC_{idling} \tag{11}$$

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 1: 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

5. Chapter 5

This chapter discusses the scope of energy conservation so as to increase the vehicle efficiency addressing the energy and emission scenarios. Emissions per passenger-km for conventional vehicles (Figure 9, 10) have been calculated based on emission factors. Emission related to electric vehicles (EVs) (Figure 11, 12) based on energy mix characteristics of the corresponding charging regime has been also evaluated. Scope of energy conservation has been discussed based on efficient operation of vehicles with respect to vehicle loading and discussion on varying the powertrain from ICE engines to EVs.

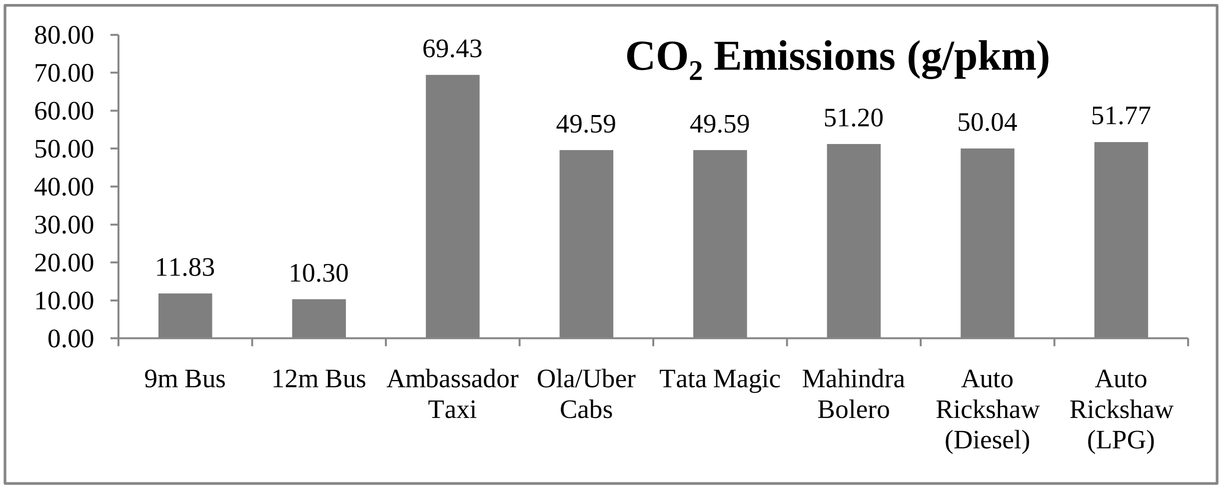

Figure 9: CO_2 emissions from different types of ICE vehicles

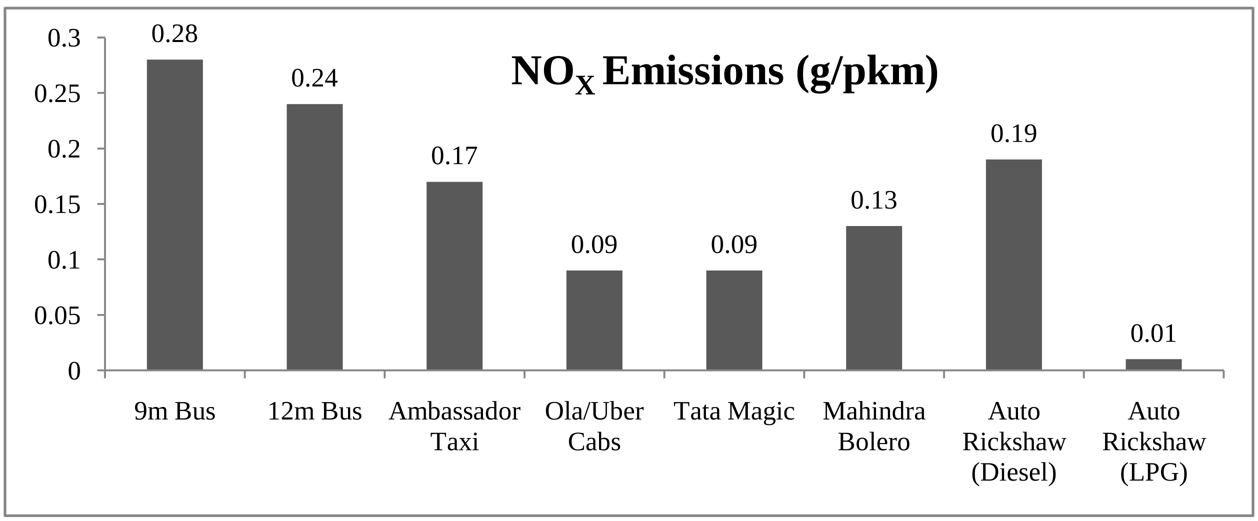

Figure 10: NO_X emissions from different types of ICE vehicles

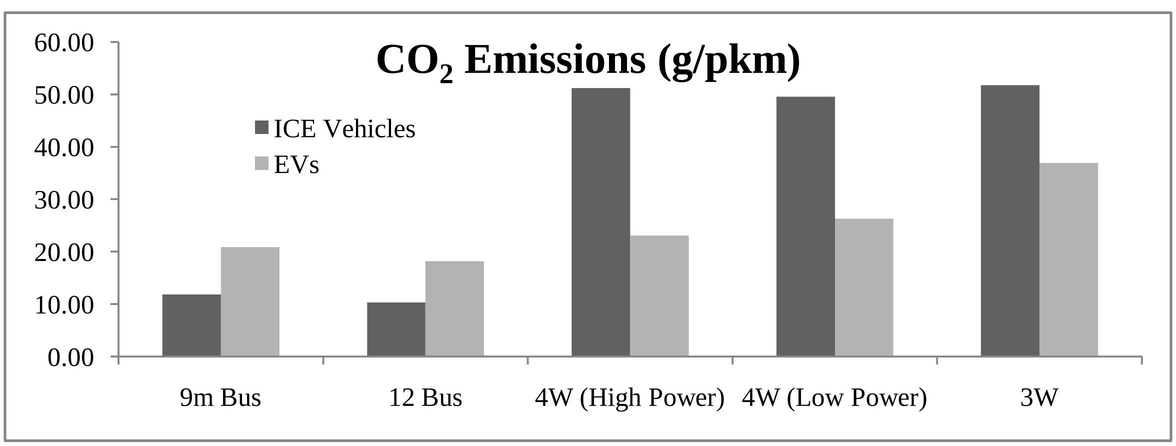

Figure 11: CO_2 Emissions comparison for EVs

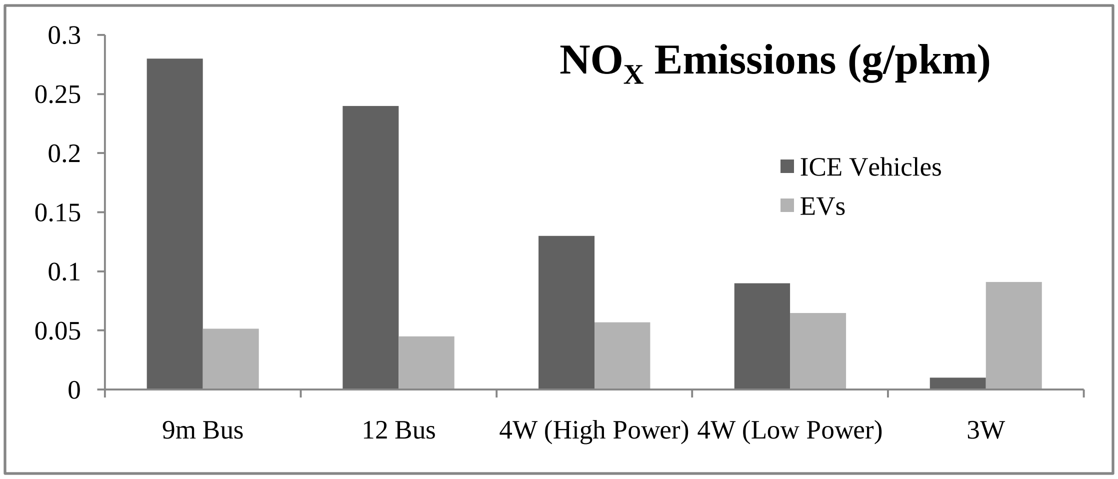

Figure 12: NO_X Emissions comparison for EVs

6. Chapter 6

Chapter discusses on the conclusions and the future scope of study.

Abbreviations:

3W	Three Wheeler
4W	Four Wheeler
6W	Six Wheeler
DC	Driving Cycle
eBus	Electric Bus
ICE	Internal Combustion Engine
pkm	passenger-kilometers

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1. **Title of the thesis:**

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

2. **Name, Designation & Institution of Supervisor:**

Prof. Tushar Jash, Professor, School of Energy Studies, Jadavpur University, Kolkata, India.

3. **List of Publications:**

Peer-Reviewed / UGC approved Journals

i) **Possibilities of Private Bus Operators Adopting Electric Buses in Passenger Transport: a Case Study in Kolkata, India,** Indian Journal of Env. Protection; Accepted for Publication on 25th October 2022

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:**

i) **Variation in fuel consumption with load in private cars – scenario in real-time traffic conditions,** International Conference on Sustainable Water Resources Management Under Changed Climate 2020, March 13-15, 2020, Kolkata

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