Freight Emission Index for walled city of Ahmedabad

September 2024

HVT/111S

This research was funded by UKAID through the UK Foreign, Commonwealth & Development Office under the High Volume Transport Applied Research Programme, managed by DT Global.

Reference No.	HVT/111
Lead Organisation/ Consultant	The Urban Lab Foundation
Partner Organisation(s)/ Consultant(s)	N/A
Title	Freight Emission Index for walled city of Ahmedabad
Type of document	Project Report
Theme	Low carbon transport
Sub-theme	Freight transport
Author(s)	Abhijit Lokre, Neha Bajaj, Nayanika Misra, Aviral Goyal
Lead contact	Neha Bajaj
Geographical Location(s)	Ahmedabad, Gujarat, India
Abstract	
Road freight demand in India is expected to grow by five times by 2050, fuelling emissions and putting pressure on the challenge to decarbonise transport. Due to the short duration of this project, it specifically explores air pollution as a key factor in the degradation of historical buildings and monuments, with a focus on the walled city of Ahmedabad. The research devises a freight emissions index for heritage cities, designed to measure emissions, provide a set of key indicators for decision-makers and develop a mitigation plan for reducing freight emissions in these areas.	
Keywords	Freight, Emission, Index, Low Carbon, Transport, Sustainability, Climate
Funding	23,865.48 GBP

Contents

List of tables

List of figures

Abbreviations/Acronyms

AMC	Ahmedabad Municipal Corporation
HVT	High Volume Transport
APMC	Agricultural Produce Market Committee
GLEC	Global Logistics Emissions Council
GHG	Green House Gases
LCV	Light Commercial Vehicle
MCV	Medium Commercial Vehicle
HCV	Heavy Commercial Vehicle
PUC	Pollution Under Control
RSI	Road-Side Interview
CVC	Classified Volume Count
BS	Bharat Stage
FEI	Freight Emission Index
RSI	Road Side Interviews

Acknowledgement

We would like to extend our deepest gratitude to the individuals, organisations, and experts for extending their support and providing their valuable inputs during the course of this project.

Our sincere thanks to Dr Leeza Malik, Dr Naveen Thomas, Dr Sarath Guthikunda, Prof Shivanand Swamy, Mr Amit Bhatt, Dr Debijt Roy, Dr Neha Upadhyay, Mr Ketan Modi, Mr Sunny, Ms. Sarika Chakravarty for their expert insights. We extend our appreciation to Dr Naveen Thomas for reviewing the methodology at various stages of the project and Mr Amit Bhatt for peer reviewing our methodology.

We would also like to acknowledge the support of our survey agency Kaizen Market Research and Consultancy, along with the Agricultural Produce Market Committee (APMC) of Jamalpur and the shopkeepers and freight vehicle drivers of APMC, Kalupur Shak market, Rajnagar market, Safal Cloth Market, New Cloth Market, Ratanpol market, Gandhi Road and Relief Road.

We would like to thank The Urban Lab team especially Mr Sarang Pingle, Ms Pratha Bisani, Ms Sreenidhi Parasuram, Ms Siddhi Soni, Ms Haiya Dalal and Ms Nikita Kinge.

We also acknowledge the continued support of Luis Rojas Bonilla, Sviti Pabari, Sara Seghayer, Samuel Fookes and Francis Dangare and the entire High Volume Transport programme team as a part of the FCDO and UKAID.

Executive Summary

In India, freight transport plays a significant role, contributing 5% to the country's total GDP and providing employment to 22 million individuals annually (NITI Ayog, 2020). According to the report, India handles the movement of 4.6 billion tons of goods annually, with a total value of USD 1.14 billion. Forecasts indicate an expected increase of 7-8% in GDP over the next five years and a projected rise in transport demand from three billion tonne-km to 15.6 trillion tonne-km by 2050. In 2020, the transport sector accounted for 13.5% of India's CO2 emissions, with road transport consuming 90% of the sector's energy, heavy duty trucks (HDTs) emerged as significant contributors, responsible for 40%-50% of total road transport emissions (IEA, 2023).

The road-based freight transport scenario in India presents several challenges, including skewed modal share favouring road transport over rail, excessive diesel consumption, and low operational efficiency. Overloaded trucks, subpar fuel efficiency, and high dead kilometre percentages, increase emissions per unit of commodity transported, aggravating environmental concerns. Addressing these challenges necessitates efforts to enhance efficiency, reduce emissions, and integrate freight transport into broader urban development strategies for a sustainable future.

India at present lacks city level data to understand the impact and influence of these challenges on emissions. Secondly, the collected data requires synthesis such that it can be used by decision makers to ideate and implement emission mitigation strategies. To address this knowledge gap, the proposed study aims at developing a tool for capturing freight emissions and aiding decision-makers. The study used the case of the walled city area of Ahmedabad in Gujarat, India. Ahmedabad is the largest city in the state of Gujarat and the seventh-largest urban agglomeration in India. The city spans a municipal area of 449 sq. km with a population of 5.5 million (Census, 2011). The city is governed by the Ahmedabad Municipal Corporation (AMC). Ahmedabad is a major industrial and commercial hub, known for being a centre for pharmaceutical, chemical and textile manufacturing and distribution activity. The walled city area of Ahmedabad is located at the centre of the city. It is chosen as the study area as it observes a high freight movement due to the presence of many retail and wholesale markets in the area. The area is traditionally a central business district (CBD). Additionally, the walled city of Ahmedabad is the first UNESCO-declared ‘heritage city’ in India.

Presently, Ahmedabad has approximately 12,500 heavy commercial vehicles (HCVs), 3,400 medium goods vehicles (MGVs), and 39,700 light commercial vehicles (LCVs), registered according to Parivahan Sewa data under the Ministry of Road Transport and Highways. Out of these, 52% of vehicles across classes operate with engine types categorised as either BS 3 or lower, significantly influencing emissions generated by freight vehicles.

Freight emissions are affected by various vehicle attributes and operational characteristics. Vehicle-related attributes such as vehicle type, fuel type, maintenance practices, engine type, and technology significantly impact emissions levels. Studies have shown that the type of vehicle, particularly heavy-duty trucks, play a crucial role in emissions output due to their large size and high engine power (Li et al., 2020). Additionally, the choice of fuel type, with alternatives such as compressed natural gas (CNG) and liquefied natural gas (LNG), offers lower carbon emissions compared to conventional diesel, contributing to emissions reduction (Hao et al., 2021). Alongside vehicle features, operational performance during the freight movement also influences emissions. Load factor, empty trips, and trip utilization play critical roles in determining the efficiency of freight transport and its environmental impact. Maximising load factors up to an optimum efficiency level and reducing empty trips contribute to reducing emissions (McKinnon, 2015). Therefore, operational strategies aimed at improving efficiency, such as route load optimisation are vital for emission reduction in freight transport.

The research aims to develop a scalable methodology to prepare a Freight Emissions Index (FEI) which can be used as an assistance tool to develop commodity specific strategies for reducing freight emissions. In this research, the FEI will be useful for the decision-makers to identify commodities and processes that would enable lowering the extent and impact of emissions in the walled city of Ahmedabad. The study seeks to accomplish the following objective. Assess factors affecting freight emissions, identify the impact of factors affecting freight emissions, and develop a freight emissions index to use as a decision-making tool for mitigation strategies.

The study uses Global Logistics Emissions Council (GLEC) framework to measure carbon emissions through all types of freight movement: air, rail and road. The framework is accredited by the Green House

Gas Protocol. The calculations and guidelines related to road transport within the GLEC framework align with the standardised EN16258 methodology. The study concentrates exclusively on carbon monoxide (CO) emissions from vehicles within the walled city of Ahmedabad. While vehicle exhaust comprises various gases like CO, CO_2, NOx, HC etc. with distinct environmental impacts, the decision to prioritise CO is based on practical considerations such as data availability and time constraints. Concentration on CO will provide a direction for decision-making in terms of emissions; however, the accounting of different gases may give different results as concentration of gas depends on the type of fuel, engine and other vehicle characteristics. Capturing all gases on ground would have been useful in providing a holistic and accurate picture of emissions on ground.

The outputs of the study are a Freight Emission Index for three commodities namely perishable, electronics and an excel-based dashboard for visualisation and interpretation of the index. A knowledge dissemination workshop and webinar were conducted to share findings from the study with a broad audience, including decision-makers, academia, students, and professionals. The mitigation and reduction strategies developed as part of the study highlight the need for a multi-pronged approach that encompasses policy initiative, regulatory framework, enforcement, design innovation, and technological applications. The study aimed to develop a method to set emission reduction targets and empirically test the impact of strategies on emission levels. The findings highlight that fuel type and vehicle age have the highest impact on the efficiency of freight emission. However, emission reduction can be achieved by improving the operational efficiency of freight movement.

1. Background

The freight and logistics sector contributes 13-14% of India's GDP (Government of India, Ministry of Finance , 2021-22). It plays an important role in economic growth. As the economy expands, the demand for goods and its accompanying freight movement will inevitably expand. In India, the freight demand is expected to triple. Nearly 70% of the freight movement in India is catered by road transport, of this, 90% is diesel-based (NITI Ayog, 2020). The inevitable increase in demand, and the skewed reliance on diesel-based transport, poses a significant concern towards climate change mitigation. Freight transportation contributes to 8% of the total greenhouse gas emissions GHG) globally. The emissions are expected to double by 2050 (Rogelj, 2018).

With rising temperatures, growing climate concerns world over and the significant effect of emissions on public health, it is crucial to monitor freight emissions at both macro and micro-level so that appropriate emission reduction strategies can be developed.

The transport sector is responsible for significant consumption of oil in India. Much of the transport sector, especially freight, heavily relies on fossil-fuel-based sources like diesel and petrol. The transport sector accounted for 50 percent (IEA, 2020) of India's oil consumption. Out of this, freight vehicles, which make up 5% of the on-road vehicles, contribute to one-third of the transport-related CO2 emissions. Freight vehicles consume 28.25% of India's diesel and contribute 34% of road transport emissions (Sharvari Patki, 2023).

India, at the 26th session of the United Nations Framework Convention on Climate Change (COP 26) in November 2021, announced its target to achieve Net Zero Emissions by 2070. India has made a commitment to convert all its on-road vehicles, including passenger and freight vehicles, to greener energy sources. This initiative requires evidence-based and data-backed policy and planning from decision-makers. Transport data is key. While freight data is available at an aggregate national level, limited data is available at the state level. Almost negligible data is available at the city level, and the area-based understanding of freight remains non-existent. Cities in India lack the data and information required to understand the implications of actions and their impact towards mitigating GHG emissions. Without empirical data, decision-makers are unable to set measurable and quantifiable emission reduction targets. The understanding of emissions at the city level is also critical in establishing national emission reduction goals for nationally determined contribution (NDC). To accurately measure freight's contribution to emissions and develop mitigation strategies, there is a need for disaggregated freight data at the city-level and assess the implications on emissions. The required data includes:

- Size of consignment
- Volume of goods moved
- Type of vehicle used
- Origin and destination of the freight movement

This study is focused on the measurement of freight emissions concerning the commodity type and vehicle characteristics and to develop a freight emission index. This index was envisioned to be designed as a tool that can aid decision-makers in developing policies and actions based on empirical evidence and quantifiable benefits. The index aims at understanding the degree of impact of potential actions. To model this tool, the study used the case of the walled city area in the city of Ahmedabad in Gujarat, India, to measure freight emissions.

1.1 Introduction

1.1.1 Current and future scenario of freight in India

In India, freight transport plays a significant role, contributing 5% to the country's total GDP and providing employment to 22 million individuals annually (NITI Ayog, 2020). According to the report, India handles the movement of 4.6 billion tons of goods annually, with a total value of USD 1.14 billion. Forecasts indicate an expected increase of 7-8% in GDP over the next five years and a projected rise in transport demand from three billion tonne-km to 15.6 trillion tonne-km by 2050. Currently, road-based modes dominate freight transport, constituting 70% of freight activity in India. The growth will be the most significant for road-based modes.

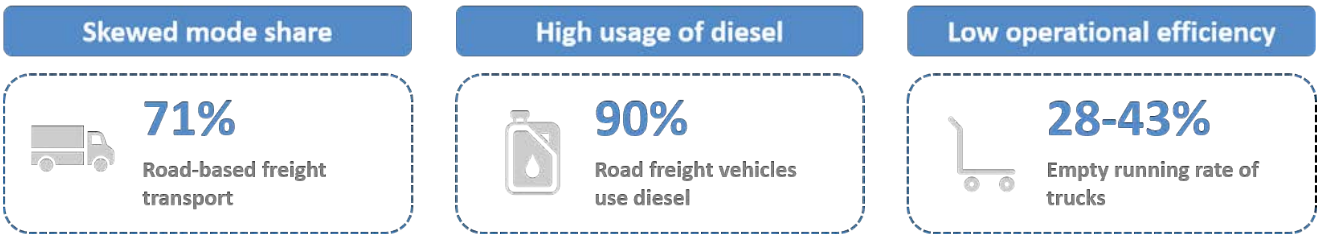
However, this expansion in freight activity comes with environmental consequences in the form of increased carbon dioxide (CO_2) emissions. In 2020, the transport sector accounted for 13.5% of India's CO_2 emissions, with road transport consuming 90% of the sector's energy. heavy duty trucks (HDTs) emerged as significant contributors, responsible for 40%-50% of total road transport emissions (IEA, 2023). Despite these alarming figures, freight transport receives limited attention in city development plans, leading to inefficiencies in operations due to a lack of coordinated urban freight policies and infrastructure imbalances.

The road-based freight transport scenario in India presents several challenges, including skewed modal share favouring road transport over rail, excessive diesel consumption, and low operational efficiency. Overloaded trucks, subpar fuel efficiency, and high dead kilometre[1] percentages increase emissions per unit of commodity transported, aggravating environmental concerns. Addressing these challenges necessitates efforts to enhance efficiency, reduce emissions, and integrate freight transport into broader urban development strategies for a sustainable future.

NITI Ayog in its national-level freight report, ‘Fast Tracking Freight in India’ (2021), highlights the following scenario of road freight transport in India:

- **Skewed modal share**: Road transport carries about 71% of India's freight, with rail making up only 17.5%. Road-based freight transport mode consumes more energy, emits higher CO_2 levels, and incurs greater costs while being more accident-prone compared to alternatives like rail and water-based transport. Moreover, India heavily relies on overloaded trucks as a practice to reduce costs, this leads to elevated air pollution and a higher incidence of traffic fatalities.
- **Excess consumption of diesel and other polluting fuels**: In comparison to countries like the USA and China, heavy-duty vehicles in India have lower fuel efficiency, resulting in increased fuel consumption and higher associated costs. Approximately 90% of road freight movement is diesel-based (measured in terms of vehicle km travelled or VKT).
- **Low operational efficiency:** Road-based transport records lower efficiency as compared to global standards. Trucks in India have an average daily run of 300 km as compared to the worldwide average of 500 to 800 km per day. Smaller truck sizes, frequent overloading, and up to 40% dead km or empty runs are some of the key inefficiencies in road transport in India. This results in a higher kilometre run per unit of commodity transported that yields higher emissions per unit of commodity transported.

Figure 1: Inefficiencies in freight transport



Source: Adapted from Transforming Trucking in India (NITI Ayog, RMI 2022)

1.1.2 Study area

1.1.2.1 City of Ahmedabad

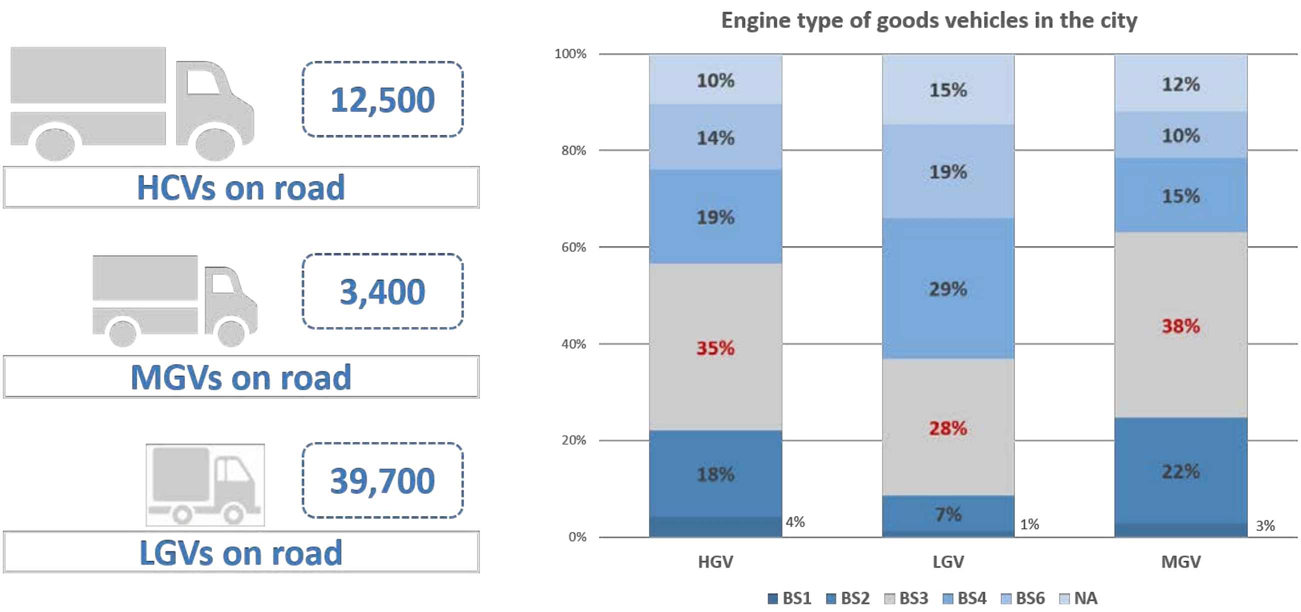
To develop a tool for capturing freight emissions and aid decision-makers, the study used the case of the walled city area of Ahmedabad in Gujarat, India. Ahmedabad is the largest city in the state of Gujarat and the seventh-largest urban agglomeration in India. The city spans a municipal area of 449 sq. km with a population of 5.5 million (Census, 2011). The city is governed by the Ahmedabad Municipal Corporation (AMC). Ahmedabad is a major industrial and commercial hub, known for being a centre for pharmaceutical, chemical and textile manufacturing and distribution activity. The walled city area of Ahmedabad is located at the centre of the city. It is chosen as the study area as it observes a high freight movement due to the presence of many retail and wholesale markets in the area. The area is traditionally

[1] Dead km, also known as deadheading or empty running, refers to when a freight vehicle, like a truck or cargo container, moves without carrying cargo.

a central business district (CBD). Additionally, the walled city of Ahmedabad is the first UNESCO-declared 'heritage city' in India.

Presently, Ahmedabad has approximately 12,500 heavy commercial vehicles (HCVs), 3,400 medium goods vehicles (MGVs), and 39,700 light commercial vehicles (LCVs), registered vehicles according to Parivahan Sewa data under the Ministry of Road Transport and Highways. Out of these, 52% of vehicles across classes operate with engine types categorised as either BS 3 or lower, significantly influencing emissions generated by freight vehicles.

Figure 2: Freight vehicles in Ahmedabad



Source: Based on data on the Parivahan dashboard by the Ministry of Road Transport and Highways

1.1.2.2 Walled city of Ahmedabad

The walled city of Ahmedabad was declared the first World Heritage City in India by the United Nations Educational, Scientific and Cultural Organization (UNESCO) in 2017. Most Indian cities have an old city centre that now primarily serves as the traditional wholesale market at the heart of the city. These markets are pivotal to the city's economic activities as they serve as points of aggregation in the supply-chain of goods being transported in and out of the city. Such centres observe a significant contribution of freight towards emission due to high freight movement.

The walled area of Ahmedabad has the following features, which are also common across the old city areas in India:

- **High economic activity:** City centres are traditional central business district (CBD) areas, and continue to function as one, with the presence of key wholesale and retail markets and warehouses.
- **Dense built form:** The walled city area was established in 1411 AD and the urban fabric was designed for movement on foot. The area has limited right of way (RoW) for secondary and tertiary roads ranging from 3m to 9m. The area contains densely packed neighbourhoods and markets, which reduces the potential for major infrastructural changes in the fabric. It also limits the size of vehicles that can use the major roads.
- **Presence of heritage structures:** The walled city area has 28 monuments listed by the Archaeological Survey of India (ASI) and 2,696 important buildings protected by the Heritage Department at the Ahmedabad Municipal Corporation (AMC). These monuments are susceptible to degradation through pollution.

The walled city area is vibrant, where wholesale and retail activities co-exist. The markets cater to a wide spectrum of commodities: textiles, consumer goods, industrial and construction materials, food grains, and shipping cargo. Freight transported from various locations in India enters Ahmedabad through major HCV entry points namely: Ognai, Naroda, Odhav in the north of the city and Sanathan, Kamod, and Aslali in the south of the city. The freight enters the walled city through four main entry points, as seen in figure 3 - Major freight routes in Ahmedabad.

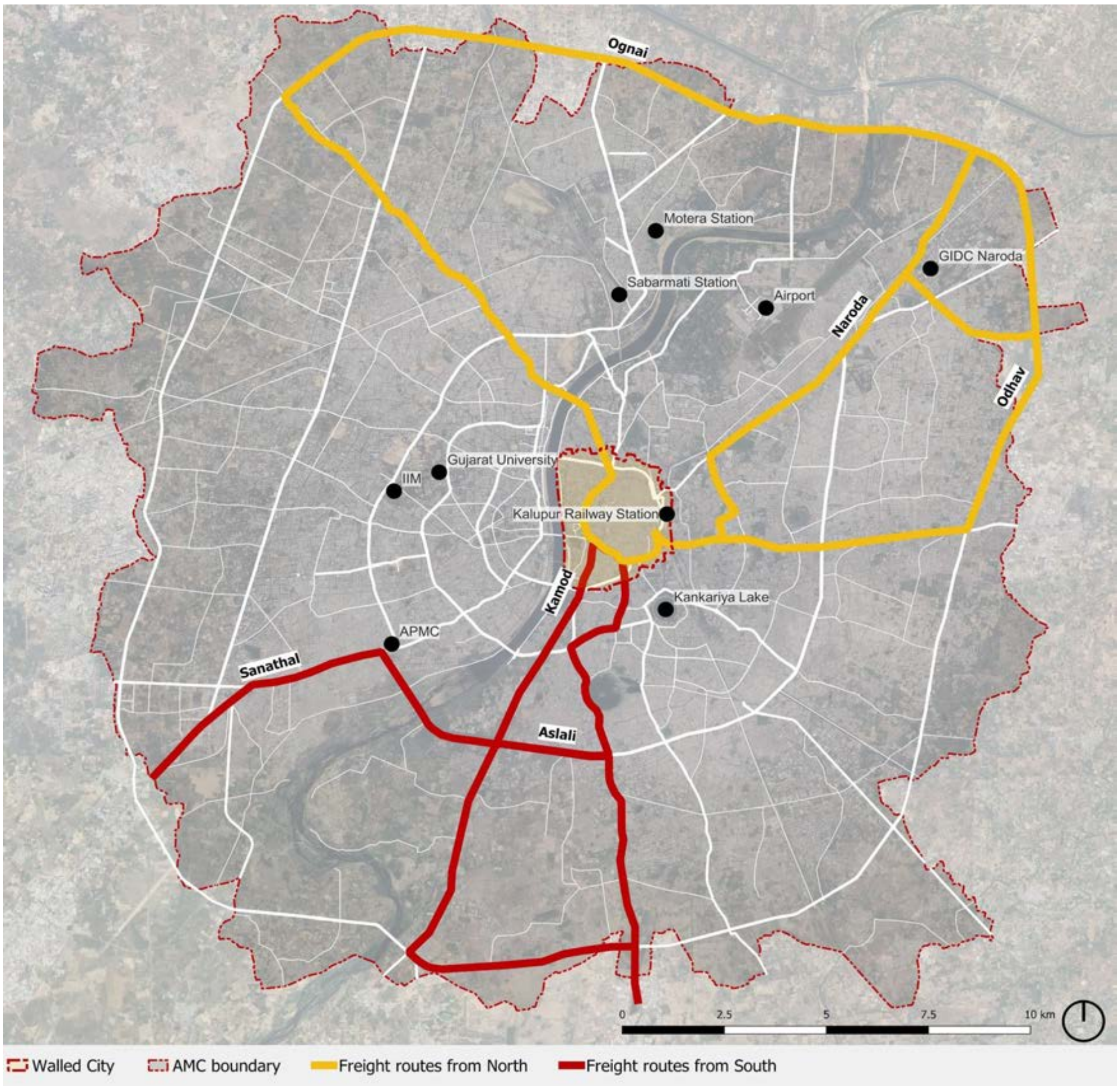
On the periphery of the walled city, there are numerous local warehouses, transportation and logistics hubs, large markets, and shopping malls. Many HCVs load the freight into smaller non-freight vehicles to transport the commodities to internal retail stores, warehouses or storage. HCVs require a specific RoW due to their size and can only access specific routes within the walled city. Routes with limited RoW are accessed through three-wheelers or two-wheelers as freight vehicles. The major internal streets in the heritage city have commercial fronts and are packed with freight movement all day.

For the study, the heritage city boundary and the buffer areas in the city centre of Ahmedabad will be used. This comprises an area of 8.1 sq. km, as defined by UNESCO. The blue area indicates the buffer zone, and the red boundary indicates the heritage city, as defined by UNESCO (see figure 4 - Base map for walled city of Ahmedabad).

The study area comprises:

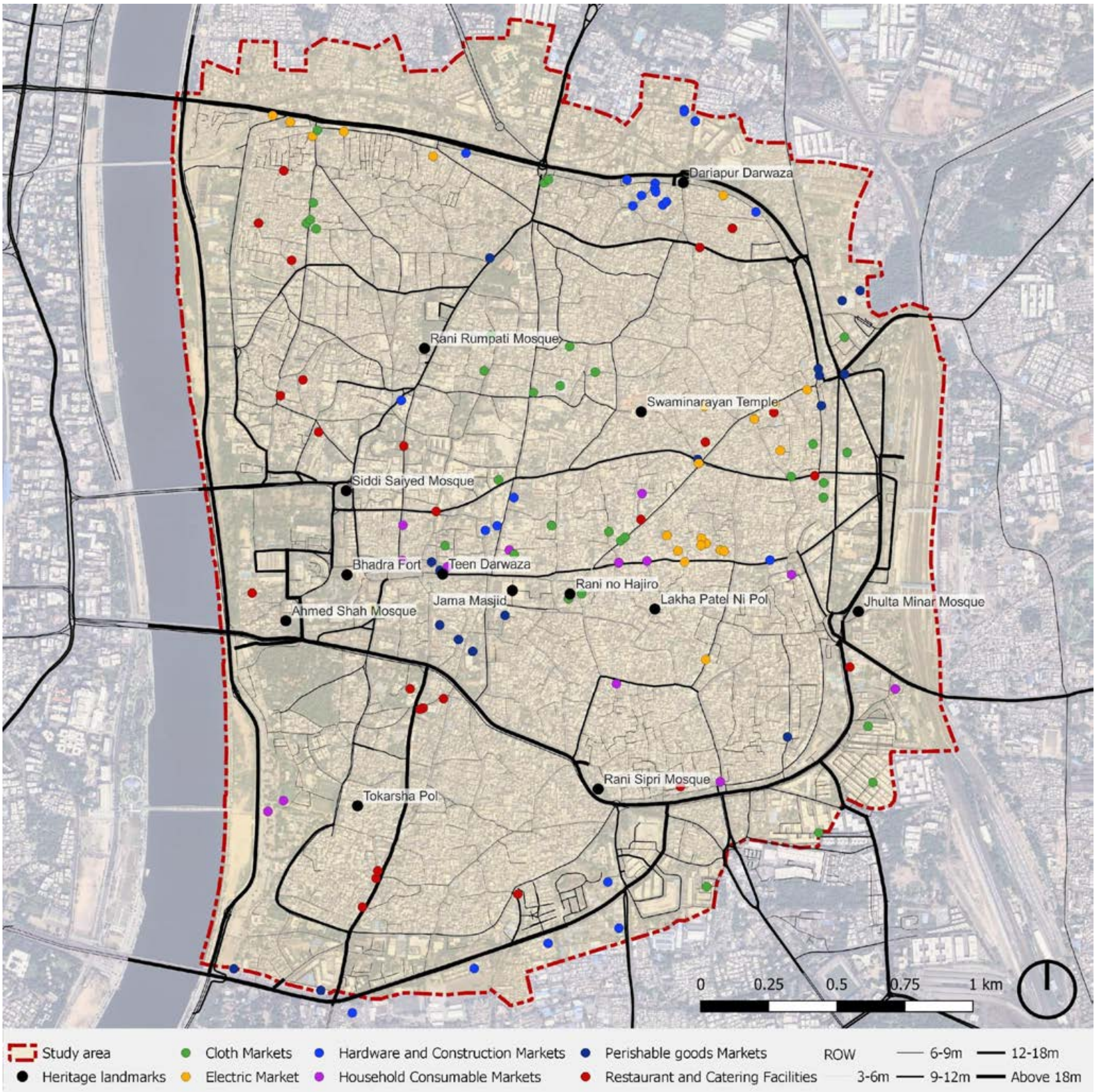
- **Major markets in the city:** APMC Jamalpur, Rajnagar vegetable market, Manek chowk food market, Kalupur fruit market, Jamalpur flower market
- **Major transit nodes:** Lal-Darwaja bus terminal, Geeta Mandir bus terminal, Kalupur railway station, Shahpur metro station, Gheekanta metro station
- **Smaller retail and wholesale markets:** Multiple smaller markets in the walled city deal in both wholesale and retail sales. These markets were identified within the study area to better understand the nature of freight patterns, supply chains, and spatial distribution.

Figure 3: Major freight routes in Ahmedabad



Source: TUL Foundation

Figure 4: Base map for walled city of Ahmedabad



Source: TUL Foundation

Figure 5: Heritage Cities in India

Source: TUL Foundation

2. Freight Emissions and Indexing

2.1 What affects emissions?

Freight emissions are affected by various vehicle attributes and operational characteristics. Vehicle-related attributes such as vehicle type, fuel type, maintenance practices, engine type, and technology significantly impact emissions levels. Studies have shown that the type of vehicle, particularly heavy-duty trucks, play a crucial role in emissions output due to their large size and high engine power (Li et al., 2020). Additionally, the choice of fuel type, with alternatives such as compressed natural gas (CNG) and liquefied natural gas (LNG), offers lower carbon emissions compared to conventional diesel, contributing to emissions reduction (Hao et al., 2021). Proper maintenance practices, including regular inspections and adherence to maintenance schedules, are essential for optimising vehicle performance and minimising emissions (Yu & Chen, 2018). Furthermore, advancements in engine technology, such as clean diesel and hybrid systems, provide opportunities to reduce emissions while improving fuel efficiency (Zhu et al., 2022).

Alongside vehicle features, operational performance during the freight movement also influences emissions. Load factor, empty trips, and trip utilisation play critical roles in determining the efficiency of freight transport and its environmental impact. Maximising load factors up to an optimum efficiency level and reducing empty trips contribute to reducing emissions (McKinnon, 2015). Therefore, operational strategies aimed at improving efficiency, such as route load optimisation are vital for emission reduction in freight transport.

The Avoid-Shift-Improve approach is an established framework to reduce transport emissions, initially developed in 1994 in a report presented in the German parliament titled, “Towards Sustainable Development: A Long-Term Program for Germany”. It is based on the idea that there are three main principles in reducing transport emissions: avoid unnecessary trips, shift to less-carbon-intensive modes of transport, and improve the efficiency of vehicles and infrastructure. McKinnon builds on the principles of Avoid, Shift and Improve in the context of freight emissions:

1. **Reduce transport intensity** – reducing road tonne-km/ GDP
2. **Alternative freight modal use** – displacing freight to alternative modes
3. **Improve vehicle utilization** – improving vehicle-km/ tonne-km use

The guidebook highlights the role of efficiency in improving emissions of transported goods. It covers the ‘small order problem’ stating that dispersal of freight in small consignments by poorly loaded vehicles to a multitude of locations was found to impose high economic and environmental costs (McKinnon, 2015). Reducing emissions requires innovative freight management solutions such as optimising routes, restructuring freight road networks within the supply chain, improving vehicle utilisation, increasing fuel efficiency, consolidating commodities, using sustainable city logistics strategies, including regulation and policy measures.

The following section dives into numerous studies and existing literature to explore the relationship between freight, logistics, and emissions. This literature review aims to determine the intersection between logistics and emissions, outline the steps for calculating the carbon footprint of supply chains, examine the existing methods for calculating emissions and creating indexes and consider how these concepts can steer the adoption of green logistics practices.

2.1.1 Vehicle characteristics

The primary aspect affecting vehicle emissions include:

- **Vehicle type and emissions:** Research has highlighted the significant impact of vehicle type on emissions in freight transport (Guan et al., 2017; Chen & Zhang, 2019). Studies have shown that heavy-duty trucks emit higher levels of pollutants compared to light-duty vehicles, primarily due to their larger size and higher engine power (Li et al., 2020). Understanding the emissions characteristics of different vehicle types is crucial for implementing targeted mitigation strategies.
- **Vehicle age and emissions performance:** The age of freight vehicles is a critical factor influencing emission performance (Wang & Zhang, 2018; Liu et al., 2020). Older vehicles often lack modern emission control technologies and exhibit higher levels of pollutant emissions per unit

of distance travelled (Cheng et al., 2019). Retrofitting or replacing older vehicles with newer, more efficient models can lead to substantial reduction in emissions and fuel consumption (Yang et al., 2021).

- **Engine type and emissions control:** The type of engine used in freight vehicles play a significant role in determining emissions level (Wu & Huo, 2019; Zhang et al., 2020). Diesel engines, commonly used in heavy-duty trucks, are associated with higher emissions of nitrogen oxides (NOx) and particulate matter (PM) compared to alternative fuel engines such as natural gas or electric (Zheng et al., 2021). Advances in engine technology, such as clean diesel and hybrid systems, offer opportunities to reduce emissions while improving fuel efficiency (Zhu et al., 2022).
- **Fuel type and emissions reduction:** The choice of fuel type directly impacts emissions performance in freight transport (Zhang & Wang, 2017; Li & Xu, 2020). Alternative fuels, such as compressed natural gas (CNG) and liquefied natural gas (LNG), offer lower carbon emissions and reduced air pollutant emissions compared to conventional diesel (Hao et al., 2021). Transitioning to cleaner fuels can contribute to significant reduction in greenhouse gas emissions and improve air quality in urban areas (Zou et al., 2021).
- **Maintenance practices and emission control:** Effective maintenance practices are essential for ensuring optimal vehicle performance and emissions control (Yu & Chen, 2018; Xie et al., 2020). Regular inspections, tune-ups, and adherence to manufacturer-recommended maintenance schedules help identify and address issues that could compromise vehicle efficiency and increase emissions (Huang et al., 2021). Proper maintenance of emission control systems, such as exhaust gas recirculation (EGR) and diesel particulate filters (DPF), is critical for minimising emissions and achieving regulatory compliance (Chang et al., 2022).

2.1.2 Operational efficiency

While the main factor affecting emissions is the vehicle's technical characteristics, studies have established the role of operational characteristics. Mckinnon has multiple landmark studies on freight, logistics and green practices. In the three-edition guidebook titled 'Green Logistics: Improving the Environmental Sustainability of Logistics,' (2015), insight is given on the need to reduce freight externalities, especially its emissions. This body of research focuses on the principle of green logistics, by optimising vehicle operations and the entire logistics system as a means to reduce externalities like emissions.

In the paper titled 'Performance Measurement in Freight Transport: its Contribution to Design, Implementation and Monitoring of Public Policy' (2015), McKinnon investigates the environmental and economic impact of freight movement and its interconnectedness with efficiency. He calls operational efficiency the 'green gold' of freight movement, emphasising on efficient movement of freight and the reduction in emissions and increase in cost-efficiency as its consequence.

To measure freight efficiency, Mckinnon outlined the following key metrics:

A. **Vehicle Capacity:** This metric covers two interlinked concepts: productivity and utilisation

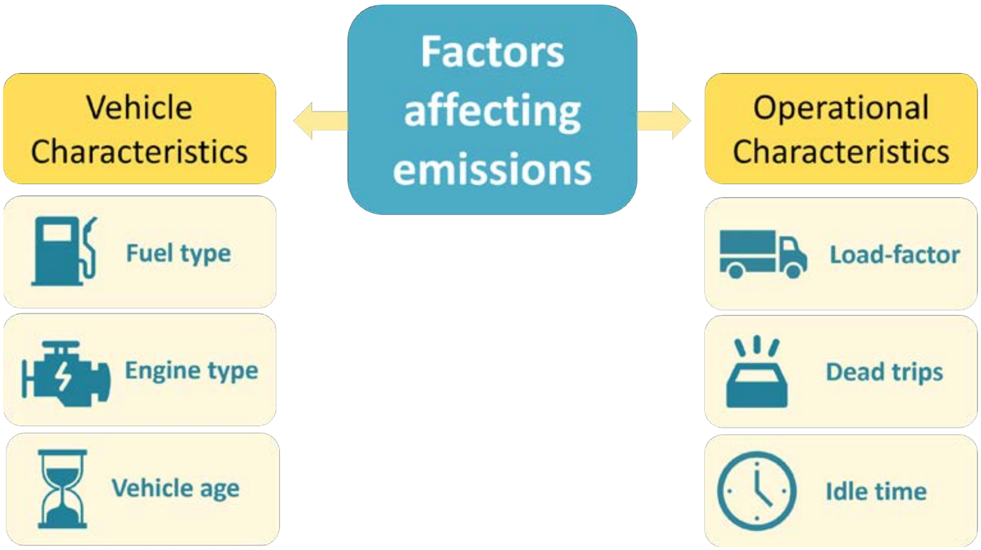
- **Productivity** refers to the ratio of outputs (such as tonne-km or vehicle-km) to inputs (such as fuel, vehicles, or labour). It measures the efficiency with which a resource is converted into an activity.
- **Utilisation** or load factor refers to the ratio of the capacity used to the total capacity available (such as the amount of space in a container occupied by a load).

Operational efficiency is especially compromised when vehicles are partially loaded or under-loaded. Both under-loading and overloading adversely affect emissions. Damage to road infrastructure due to over-loading adds to the inefficiency, due to unevenness of the road surface and delays caused by the additional maintenance that is subsequently required.

However, on-ground many factors play into maximising load-factor. Companies that do not fully load their vehicles may make the rational decision to balance transport efficiency with other business objectives, such as minimising inventory, optimising warehouse space, or maximising loading bay staff productivity. Consequently, the weightage or effect of operational efficiency on emissions depends on the scope and intention for emission calculation.

B. **Fuel Efficiency:** Fuel efficiency is a measure of how efficiently energy is converted into moving freight and can be expressed as either fuel efficiency per vehicle-kilometre or using a denominator that considers the weight or volume of goods transported, often referred to as "energy intensity." Fuel efficiency is measured by calculating the vehicle-kilometres travelled by vehicles multiplied by an average fuel efficiency metric (typically measured in litres per 100 kilometres). The metric is developed through operator surveys or drive cycle testing.

Figure 6: Factors affecting freight vehicle emissions



2.2 What is carbon accounting?

In the area of climate management, carbon accounting serves as a comprehensive system which aims to measure the greenhouse gas emissions of various entities, ranging from entire companies to specific aspects like manufacturing units, employee activities, or even supply chains. Within this larger framework, measuring emissions from freight transport represents one component. Carbon accounting encompasses the broader task of providing data on all greenhouse gas emissions associated with a particular system or activity, allowing for a holistic understanding of its environmental impact.

Emission calculation is part of the larger umbrella of the carbon foot printing process. Carbon foot printing is the entire process of accounting for the total greenhouse gas emissions that are directly or indirectly caused by an individual, organisation, event, or product (Carbon Neutral n.d.). Below is an overview of the steps for carbon foot printing as provided by McKinnon (2015) in the context of freight logistics:

- **Step 1: Setting an objective for emission calculation**

Objectives of emissions, based on the purpose of the study, determine the methodology of calculating emissions. Objectives prioritise factors and determine the weightage given to them. For instance, the objective may be to enhance a company's compliance with regulations, optimise resource utilisation, and lower energy consumption. Additionally, the intended audience for emission accounting, a company's perspective or decision-makers, can influence the approach.

- **Step 2: Selecting the calculation approach and establish the boundary**

This step outlines the scope of calculations and specifies the extent of the supply chain which is to be covered. It involves defining the scope of emissions to be calculated, which dictates the type of calculation to be applied. This stage impacts various factors: the data type, the count of facilities considered, and the inclusion or exclusion of specific operations. Emissions are typically categorised into three scopes, as initially outlined by the Greenhouse Gas Protocol (GHG Protocol):

1. **Scope 1:** It covers direct emissions stemming from assets owned and under the company's control. It includes emissions resulting from fuel combustion for power, heat, and transportation, as well as fugitive emissions like methane leaks from natural gas pipelines.
2. **Scope 2:** It covers indirect emissions associated with purchased electricity, steam, heating, and cooling systems used by the company.

3. **Scope 3:** These are supply chain emissions, specifically the emissions generated during the transportation of goods from suppliers to the company.

- **Step 3: Data collection and selecting emission factors**

Data collection can take one of the two approaches - a top-down approach, which involves using aggregate-level data to estimate on-ground consumption, or a bottom-up approach, which relies on individual driver surveys.

- **Step 4: Calculation**

To compute emissions for a product or a commodity, it's essential to create a supply chain map. This map offers an overview of all the processes, the product undergoes at each stage throughout the entire supply chain. The emission values from each stage are then added together using a selected calculation method to determine the total carbon footprint of the product across its complete supply chain.

2.2.1 Freight emission calculation methods

The European Standard EN16258 (CEN 2015) is the only globally accepted emission calculation standard method. It establishes a common methodology for the calculation and declaration of energy consumption and GHG emissions related to any transport services (freight, passengers, or both) and specifies general principles, definitions, system boundaries, calculation methods, apportionment rules (allocation), and data recommendations, to promote standardised, accurate, credible, and verifiable declarations regarding energy consumption and GHG emissions related to any transport service quantified.

There are eighteen established standards, programs, tools, frameworks, and methodologies for emission calculation which are commonly in use, all are based on EN16258 (Wild, 2021).

Global Logistics Emissions Council (GLEC) framework is selected for this study as it provides a comprehensive overview of road freight emission calculations. The framework provides flexibility for application in different contexts and countries. The method is accredited by the Greenhouse Gas Protocol and has been included in the UN-led Global Green Freight Action Plan (an initiative under the Paris Agreement) and is used by more than 100 multinational companies to account for their freight emissions and optimise their freight movement. The framework intends to target all decision-makers involved in green freight programmes. The framework takes account of missing data as a key challenge in emission calculation and provides adjustments, estimates and guidance towards countering missing data and producing accurate results.

2.2.1.1 GLEC framework

The Global Logistics Emissions Council (GLEC) framework focuses on measuring carbon emissions through all types of freight movement: air, rail and road. The framework is accredited by the Green House Gas Protocol. The calculations and guidelines related to road transport within the GLEC framework align with the standardised EN16258 methodology.

The GLEC framework provides detailed guides on how to collect consistent and reliable data as well as examples of where this data can be collected. The framework highlights which type of data should not be used as a proxy, which might yield incorrect calculations. It provides various sets of advice, estimations, and adjustments which can be made if specific data is unavailable. The framework also provides fuel and emission factors, but these do not apply to India. The framework is extremely useful for its simplified and straightforward calculations of road freight emissions. It relies on data which can be obtained from drivers directly and does not rely on data collected by logistics companies. Many calculation methods rely on company-based data, which is available in the Indian context. Additionally, the data required does not involve using any measurement devices.

The GLEC framework employs a two-step approach for emission calculation:

- **Step 1: Collecting transport activity data**

Transport activity is typically quantified using "tonne-kilometre," representing the movement of one tonne of cargo over one kilometre. Tonne-kilometres for a single shipment is calculated by multiplying the weight of the cargo by the travelled distance.

$$tonne - km = tonne\ x\ kilometre$$

Tonne-kilometres expresses the efficiency of freight transportation. It represents the amount of fuel or CO_2 equivalent emissions used to move the total cargo over the total distance covered. It is typically calculated over a year to account for seasonal variations and outlier values.

$$Fuel\ or\ CO_2e\ intensity\ factor = \frac{\sum_1^n (kg\ fuel\ or\ CO_2e)}{\sum_1^n (tonne - km)}$$

To find the total tonne-kilometres for a set of consignments, the weight and loaded distance are multiplied together for each consignment and then the individual tonne-kilometre values are added together.

$$\sum_{trip=1}^{n} tkm = tonne_{trip1}\ x\ kilometre_{trip\ 1} + tonne\ x\ kilometre \ldots\ldots + \ tonne_{trip\ n}\ x\ kilometer_{trip\ n}$$

- **Step 2: Converting activity data to emissions:**

  Once the transport activity data is collected, it is converted into emissions figures. This can be done using two approaches:

a. **Fuel efficiency factor**

This step must be carried out separately for each type of fuel.

$$kg\ CO_2e\ emissions = \sum_1^n \left(total\ tkm\ x\ fuel\ efficiency\ factor\ \left(\frac{kg\ fuel}{tonne - km}\right)\ x\ fuel\ emission\ factor\ \left(\frac{kg\ CO_2}{kg\ fuel}\right)\right)$$

b. **CO_2e intensity factor**

$$kg\ CO_2e\ emissions = \sum_1^n \left(total\ tkm\ x\ CO_2e\ intensity\ factor\ \left(\frac{kg\ CO_2}{tonne - km}\right)\right)$$

2.3 Review of Indexes

The study by McKinnon (2015) underscores the importance of measuring the performance of freight transport and its close relationship with transport efficiency. The author outlines several indicators and metrics to gauge the performance of freight transport, including freight transport intensity, freight modal split, and market density. Freight transport intensity measures the ratio of freight tonne-km to an economic output measure, indicating the economy's reliance on freight transport. The freight modal split assesses the dominance of road freight over rail freight in national markets, with implications for emissions and congestion policies. Market density evaluates the diversity and competitiveness of logistic services, impacting demand mix and modal use.

The "Sustainable Urban Transport Index (SUTI)," developed by the Economic and Social Commission for Asia and the Pacific, is an Excel-based tool aimed at summarising, monitoring, and comparing sustainable urban transport system performance. This index relies on ten indicators encompassing various aspects of the transport system, social, economic, and environmental dimensions. On the other hand, "Transport Sustainability Index: An Application of Multicriteria Analysis" (2022) by Rodrigues and colleagues utilises fuzzy logic principles to assess emissions and measure the environmental impact of transportation. This index employs a multi-criteria analysis grounded in fuzzy logic to evaluate the overall sustainability of the transport system, gathering performance indices related to transportation activities and the environment.

Additionally, the paper "Assessing Transport System Sustainability through Index: A Review" (2022) by Ayadi et al. conducts a comprehensive literature review on transport sustainability using composite indicators. The study analyses trends in existing research and offers insights into various index modelling techniques, highlighting their strengths and challenges.

Overall, most of the reviewed sustainability indexes utilise environmental, economic, and social dimensions, with some incorporating additional dimensions like political, spatial, mobility, and transport activity. The Min-Max approach is commonly used for normalisation. Weighting approaches fall into three categories: equal weighting, expert opinion-based weighting, and statistics-based weighting.

2.4 Key takeaways

- **Defining a clear purpose and identifying the audience:** It is essential to establish a well-defined purpose for conducting carbon footprint assessments like emission mapping and to identify the intended audience for the results. This clarity guides the entire process of emissions calculation, ensuring that the methodology aligns with specific objectives. Defining the purpose also helps in detailing and mapping the supply chain for emissions.
- **Focusing on vehicle characteristics:** When tracking greenhouse gas emissions, the technical aspects of a vehicle like its **fuel type, engine type, vehicle type, and age** influence its on-ground emission. Newer vehicles and vehicle technology should be encouraged and shift to greener fuel alternatives, where feasible.
- **Prioritising operational efficiency:** The efficiency of logistical operations and the efficient use of fuel are closely tied to the environmental impact of freight transportation. Effective management of these aspects can directly reduce the pollution associated with moving goods. Recognising this connection is crucial when mapping the carbon footprint of freight operations. Improving operational efficiency characteristics, like **load-factor, number of empty trips and congestion time,** is critical for reducing emissions.
- **Use of GLEC framework for emission calculation:** The Global Logistics Emissions Council (GLEC) framework is a valuable resource for greenhouse gas emissions accounting, specifically for road freight transportation. Beyond simply outlining the steps involved in emissions calculation, GLEC assists when data may be lacking or challenging to obtain.

3. Research Framework

3.1 Aim

The research aims to develop a scalable methodology to prepare a Freight Emissions Index (FEI) which can be used as an assistance tool to develop commodity specific strategies for reducing freight emissions. In this research, the FEI will be useful for decision-makers to identify commodities and processes that would enable lowering the extent and impact of emissions in the walled city of Ahmedabad.

The study will achieve the aim by addressing three key research questions.

1. How is freight transport emission and efficiency measured globally?
2. What are the key parameters to assess the level of efficiency-emission to transport freight?
3. How to measure freight emissions in the walled city of Ahmedabad?
4. What strategies can be adopted to mitigate road freight emissions?

3.2 Objectives

The study seeks to accomplish the following objectives:

1. Assessing factors affecting freight emissions
2. Identifying the impact of factors affecting freight emissions
3. Developing a freight emissions index to use as a decision-making tool for mitigation strategies

3.3 Scope of the study

- **Focus on CO emissions:** The study concentrates exclusively on carbon monoxide (CO) emissions from vehicles within the walled city of Ahmedabad. While vehicle exhaust comprises various gases like CO, CO_2, NOx, HC etc. with distinct environmental impacts, the decision to prioritise CO is based on practical considerations such as data availability and time constraints. Concentration on CO will provide a direction for decision-making in terms of emissions; however, the accounting of different gases may give different results as concentration of gas depends on the type of fuel, engine and other vehicle characteristics. Capturing all gases on the ground would have been useful in providing a holistic and accurate picture of emissions on the ground.
- **Geographical scope:** The research focuses on freight movement and related activities exclusively within the confines of the walled city of Ahmedabad. This deliberate limitation ensures a detailed examination of emissions within this specific urban context, providing valuable insights into the localised emission impact of freight operations.
- **Study outcomes:** The outcomes, conclusions, and findings derived from the study are explicitly tailored to the walled city of Ahmedabad. They are specific to the geographical area, emphasising the study's localised and context-specific nature.

3.4 Approach

The study adopts a mixed-method approach to develop the freight emission index and subsequent mitigation strategies. The team collected primary and secondary data required for developing the index and conducted in-depth discussions with market establishment owners to understand the freight movement pattern and practices in the walled city. The key indicators influencing freight transport emissions are identified through a secondary literature review and an assessment of the supply chain of commodities within the walled city.

The approach undertaken focuses on improving performance efficiency and supply-chain optimisation. The emission index and strategies prioritise improvement in operational and performance efficiency over fuel and vehicle replacement. The research approach comprises of four distinct phases (refer figure 7 - Research methodology):

- **Phase 1 - Desk review**

This phase comprised of an initial desk review. It involved comprehensive literature review for identifying the indicators for selection of an optimal index model. The selection of index model was based on exploration of three models - principal component analysis (PCA) based model, likert/adequacy scale and regression-based model. Further, a suitable carbon emission calculation method was determined through the analysis of various options. A preliminary survey questionnaire was prepared during this phase.

- **Phase 2 – Data collection**

This phase focused on data collection, commencing with a preliminary survey to map routes, ascertain road hierarchy and width, and identify key markets and commodities for the study. Primary data was collected through establishment surveys, traffic volume assessments, and roadside interviews, while secondary data was sourced through information from Regional Transport Offices, Pollution Under Control (PUC) certificates, and Air Quality Index monitoring units. Stakeholder engagement was conducted involving experts from academic, policy, and transport domains, business entities, private logistics and transport operators.

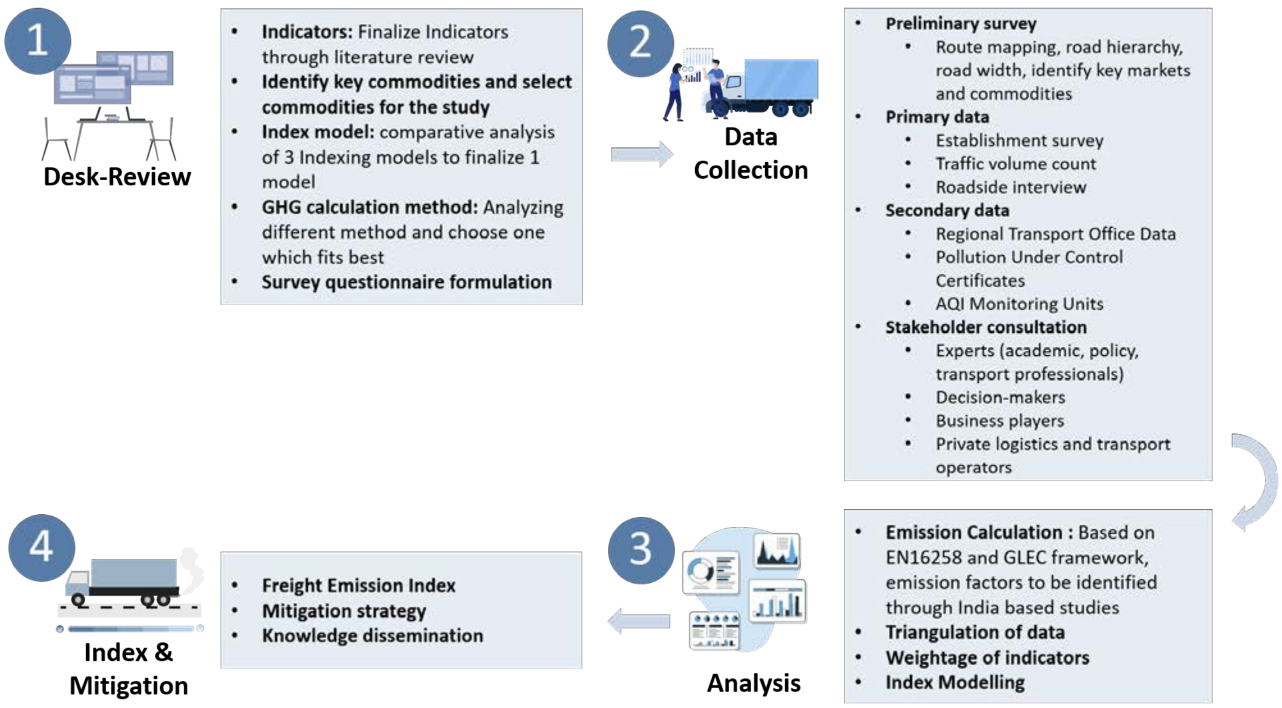
- **Phase 3 – Analysis**

The third phase centred on analysis, encompassing emission calculations identification of emission factors through India-based studies, data triangulation, indicator weighting, and index modelling.

- **Phase 4 – Emission index and mitigation strategies using index as a tool**

The fourth and final phase concluded the development of the Freight Emission Index, followed by formulation of context-based mitigation strategies, and the dissemination of acquired knowledge.

Figure : Research methodology



Source: TUL Foundation

3.4.1 Detailed methods for objective

Research techniques for each objective are detailed below (figure 8 - Method for each objective):

- **Objective 1:** Assessing factors affecting freight emissions

A desktop study involved assessing the relevance of existing emission indexes, determining transport emission calculation methods, identifying approaches for evaluating freight efficiency, and specifying necessary data requirements.

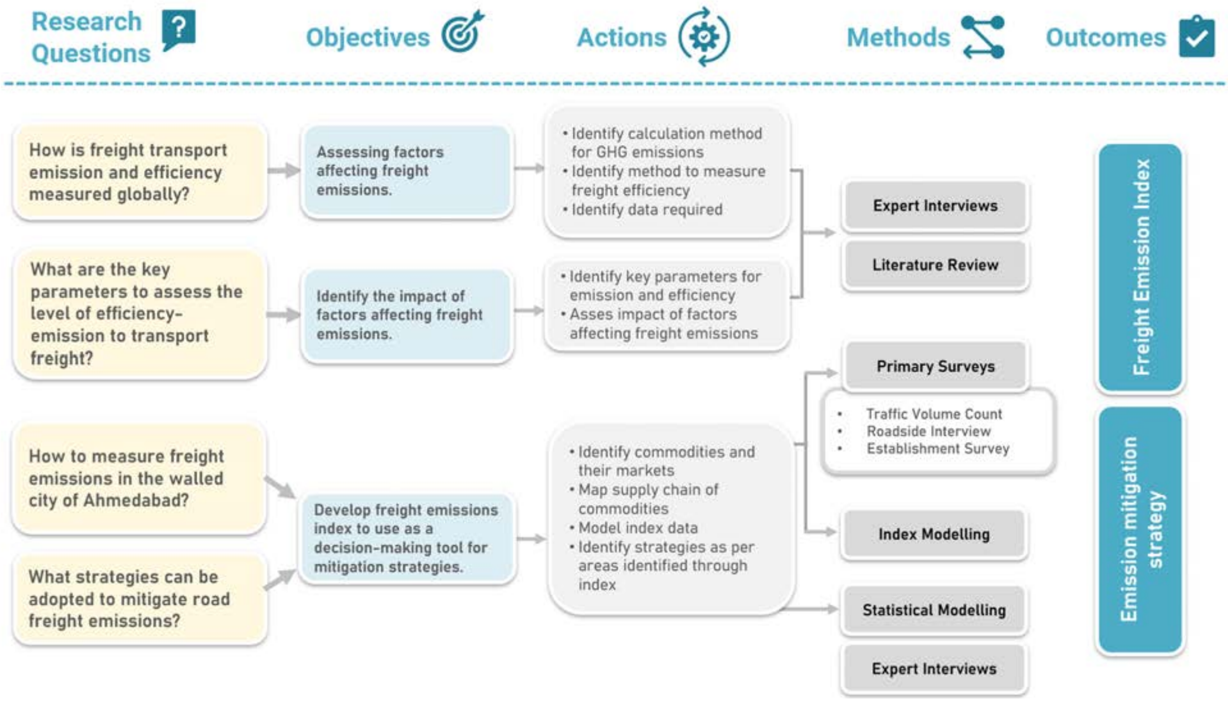
- **Objective 2:** Identifying the impact of factors affecting freight emissions

Identified key parameters in each factor which affect freight vehicle emissions. Further, assessed the magnitude of impacts of those parameters on freight emissions through expert interaction and secondary studies.

- **Objective 3:** Developing freight emission index to use as a decision-making tool for mitigation strategies

A primary investigation of the heritage city was conducted considering the key commodities identified. Primary surveys including traffic volume counts, roadside interviews, establishment surveys, stakeholder consultations, and expert interviews were conducted to assess the demand and intensity of the commodities. Further, the Freight Emission Index was developed using collected data for each parameter. Building upon the findings, mitigation strategies were developed for the walled city of Ahmedabad.

Figure 8: Method for each objective



Source: TUL Foundation

3.5 Outcome

To measure and capture freight emissions in the walled city, a Freight Emission Index was developed as a tool to assist decision-makers in developing strategies to reduce freight emissions.

The major outcomes of the study include:

1. Formulation of the Freight Emission Index as a decision-making tool
2. Developing mitigation strategies using the index to demonstrate the use of index

This encompasses the evaluation of the emission efficiency of commodities, the establishment of benchmark standards for commodities as per their comparative freight emissions, and the identification of pivotal indicators necessitating optimisation within commodities. Using the index, the study provides targeted mitigation strategies for reducing carbon emissions and enhancing operational efficiency for freight movement in the walled city of Ahmedabad.

3.6 Output

The major outputs of the study are:

- **Freight Emission Index:** Developed a comprehensive Freight Emission Index to assess and quantify emissions from freight vehicles

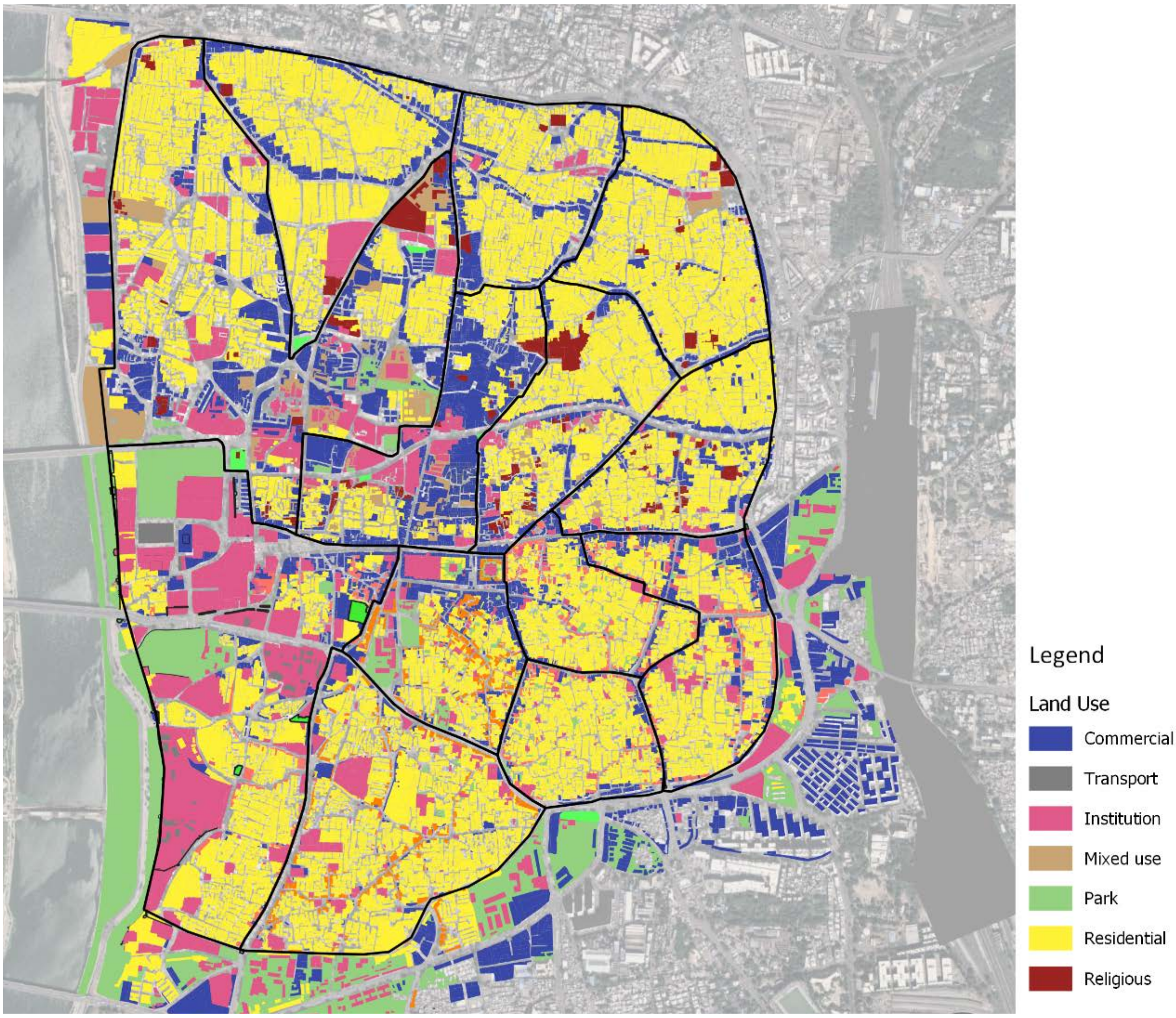
- **Excel-based dashboard:** Developed an excel-based dashboard for visualisation and interpretation of the index
- **Knowledge dissemination workshop and webinar:** Conducted a hybrid interactive workshop and an online webinar to share findings from the study with a broad audience including decision-makers, academia, students, and professionals.

4. Freight in the walled city of Ahmedabad

The walled city of Ahmedabad has a vibrant character, where wholesale and retail activities co-exist. The markets here cater to a wide spectrum of commodities that constitute textiles, consumer goods, industrial and construction materials, food grains, and shipping cargo.

The walled area is an amalgamation of diverse land-use patterns. The arterial roads majorly feature commercial use, where small to medium retail markets are present along the roads. The central region constitutes mixed-use spaces where buildings integrate institutional, commercial, and residential use. As per the land-use map, there is a high presence of commercial activity in the central region of the walled city, indicating a high frequency of freight vehicles towards the centre. Consequently, this also leads to an increase in freight movement along the arterial streets of the area.

Figure 9: Land-use in the walled city of Ahmedabad



Source: TUL Foundation

Roads on the periphery are wider than 15 metres and are accessible by HCVs. The majority of the warehouses, wholesale markets and large retail markets are located on the periphery. Only a few secondary and tertiary roads are wider than 9 metres and can be accessed by LCVs. The majority of the roads in the core area are less than 6 metres wide. The majority of the retail markets and shops are located along the narrow roads in the core city area. The market has a densely built fabric and has high pedestrian movement throughout the day. These streets are congested as it caters to heavy pedestrian movement, passenger vehicles, fright vehicles, and vendors throughout the day. Smaller freight vehicles use inner lanes for quick transportation.

Freight movement is predominantly catered by tempos, autos, two-wheelers, cycle rickshaws and handcarts for goods transportation in the areas

- Smaller freight vehicle suffices the demand for daily goods
- The size of the vehicle allows easy manoeuvring and parking for loading and unloading access to the storefronts
- The cost of transportation is comparatively lower than larger vehicles
- There is no time and parking enforcement and regulations governing the movement of smaller freight vehicles. This allows flexibility in delivery and pick-up time

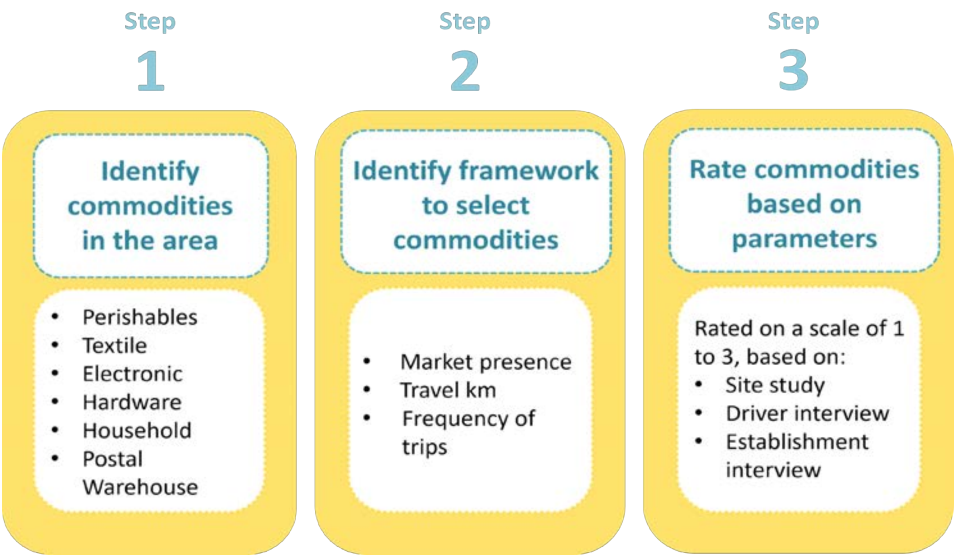
Figure 10: Passenger vehicle with freight entering the walled city

Source: TUL Foundation

4.1 Selection of commodities

Key commodities are identified for the study which will have the maximum impact on freight emissions in the area. Key commodities are identified through three phases (refer figure 11 - Process to identify commodities for the study).

Figure 11: Process to identify commodities for the study



Source: TUL Foundation

- **Step 1:** Identify all commodities in the heritage city

Based on the preliminary site study and stakeholder interactions, the following commodities are identified:

1. Perishables (fruits, vegetables, grains, flowers)
2. Household consumables (plastics, sports equipment, decorative products)
3. Postal services and warehouses
4. Electrical and electronic goods
5. Textiles
6. Hardware and construction materials (timber, sand, stone, metal sheets)

(For details on market presence refer figure 12 - All commodity markets in the walled city.)

- **Step 2:** Develop a framework guided by parameters to select commodities to study

The parameters are identified to determine which commodities have a visible impact on emissions in the area:

1. Share of market presence
2. Kilometres travelled for freight transport
3. Frequency of trips

(For a detailed description of each parameter refer table 1 - Parameters for rating commodities)

- **Step 3:** Rate commodities on the selected parameters

Each commodity is rated on the three identified parameters. These ratings are given on a scale of 1 to 3 based on site study, operator and establishment interviews and secondary data.

(For detailed ratings of each parameter refer table 2 - Rating of all commodities)

Figure 12: All commodity markets in the walled city

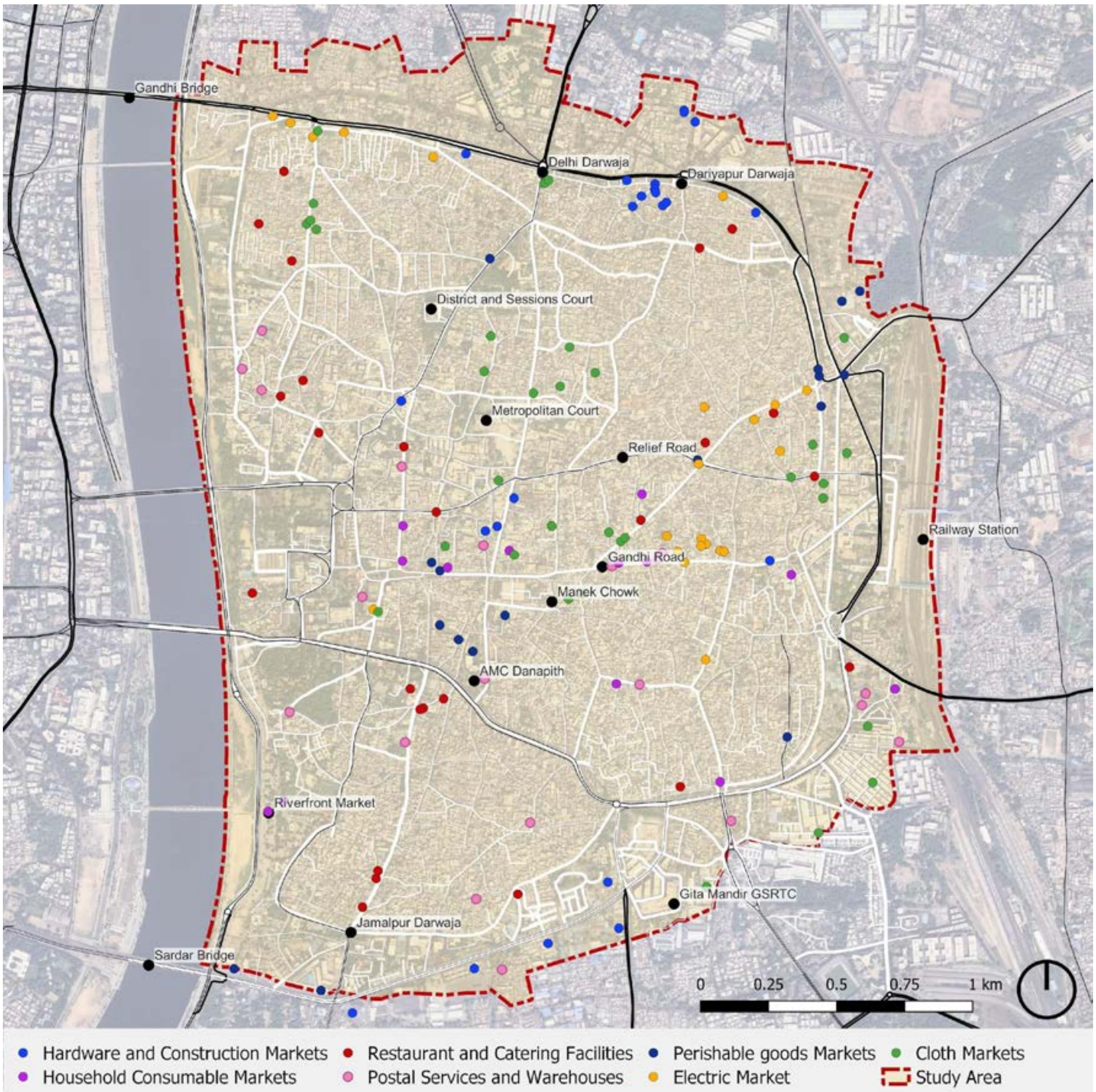


Table 1: Parameters for rating commodities

S no	Parameter	Perishable	Electricals	Textile	Hardware and construction material	Household consumable	Postal service & warehouses
1	Market presence	3	2	3	2	2	1
2	Travel km	3	3	3	2	2	1
3	Time of travel	3	2	3	2	1	2
	Total score	9	7	9	6	5	4

Table 2: Rating of all commodities

Parameters	
Market presence	1: Small shops and retail outlets 2: Sub-markets 3: Main wholesale city market
Travel kilometres	1: Point to point trade 2: Last-mile delivery 3: Both B2B and B2C trade
Time of travel	1: Non-peak hours 2: Peak hours 3: All over the day

Based on the selection criteria, the three highest-rated commodities on the basis of market presence, kilometres transported, and frequency of trips are as follows:

1. **Perishables** (fruits, vegetables, grains, flowers)
2. **Electronics** (Electricals like bulbs, tube lights, lamps, wires and electronic items like geysers, television, speakers)
3. **Textiles** (wholesale cloth like grey cloth, cotton and silk cloth, bedsheet and curtain material and ready-made garments)

The section ahead details out supply chains of the identified commodities and the calculated emissions of each commodity within the walled city area.

4.2 Textile market

The largest market presence is the textile market in the walled city area. It is a major retail and wholesale hub for manufactured textiles and ready-made garments. The majority of the textiles come from Surat, which is located around 200 km from Ahmedabad, and is India's major hub for textile production. Additionally, textile also comes from Jaipur, Mumbai, Delhi, Ludhiana. Large textile wholesale markets like New Cloth Market, Safal Cloth Market, Sumel Business Park are located at the periphery of the walled city. Approximately 30% of the consignments received here are transported to cities outside Gujarat[2].

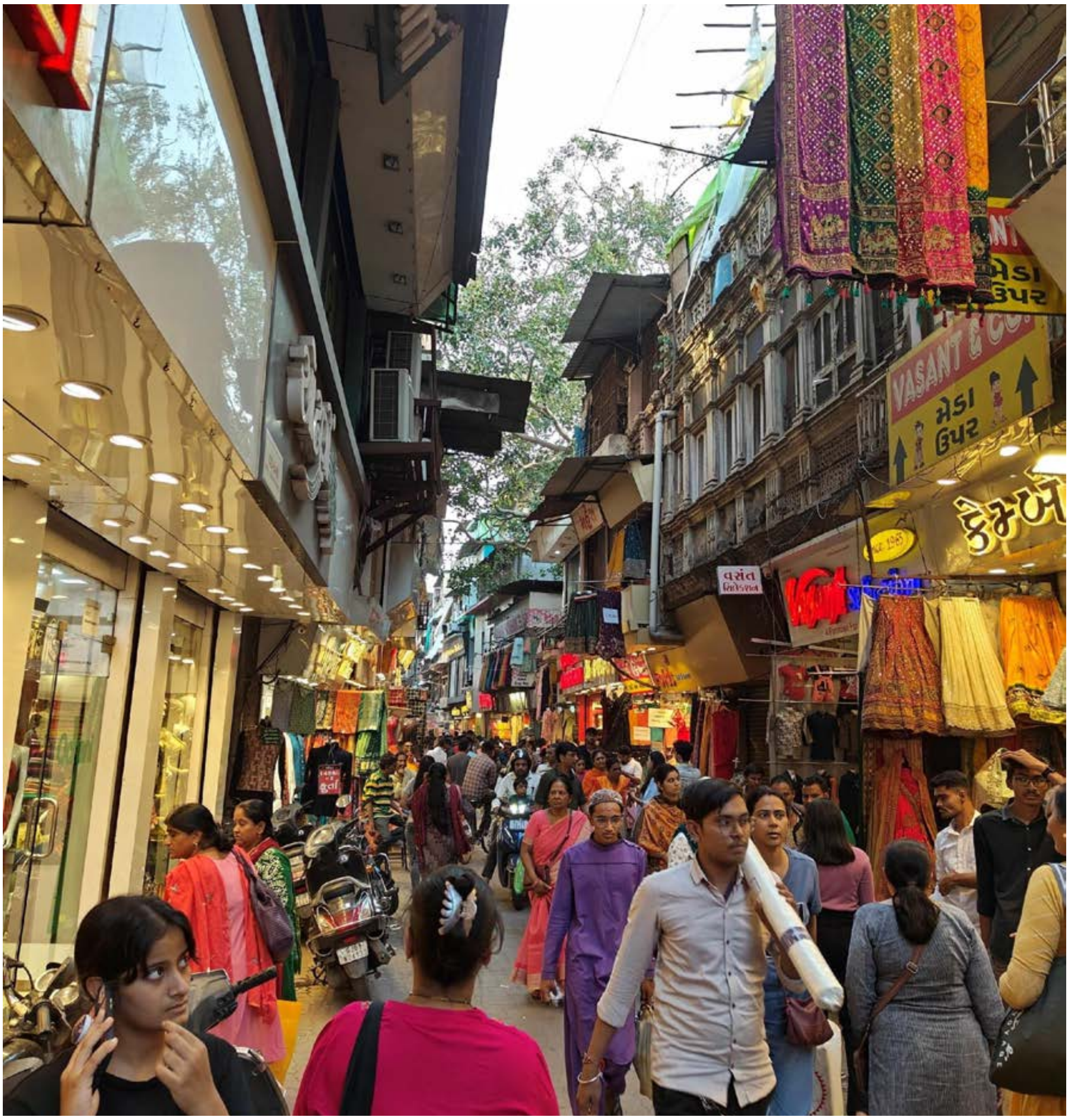
[2] Based on primary stakeholder consultation

Large retail markets in the walled city are located in the middle of the region such as Pir Mohammad Shah Road and Ratan Pol. This is a hub for readymade garments, fabrics, and grey cloth, located in the core area of the heritage city at Tankshal, Khadia. It is a small labyrinth of shops and local warehouses that is flocked by residents and tourists for shopping. It is accessible through narrow lanes of 3 metres, which are usually crowded by pedestrians, 2-wheelers, autos, and tempos (refer to figure 13 - Ratan Pol market, walled city, Ahmedabad). Textile consignments are transported from the wholesale markets located at the periphery to the retail market located inside the walled city. The freight activity here is haphazard, with disordered parking and no time restrictions for LCVs and other smaller freight vehicles. From Ratan Pol, the goods directly go to the consumers or are transported to retail shops outside the walled city. Textile freight activity functions on demand basis. As and when consignment is bought by a customer, the LCV is used to transport goods to the market from warehouses. These are transported at no specific time but are staggered throughout the day as per market timings (10 am to 7 pm).

RSI (road side interviews) with drivers and establishment surveys were conducted at the following markets inside the study area:

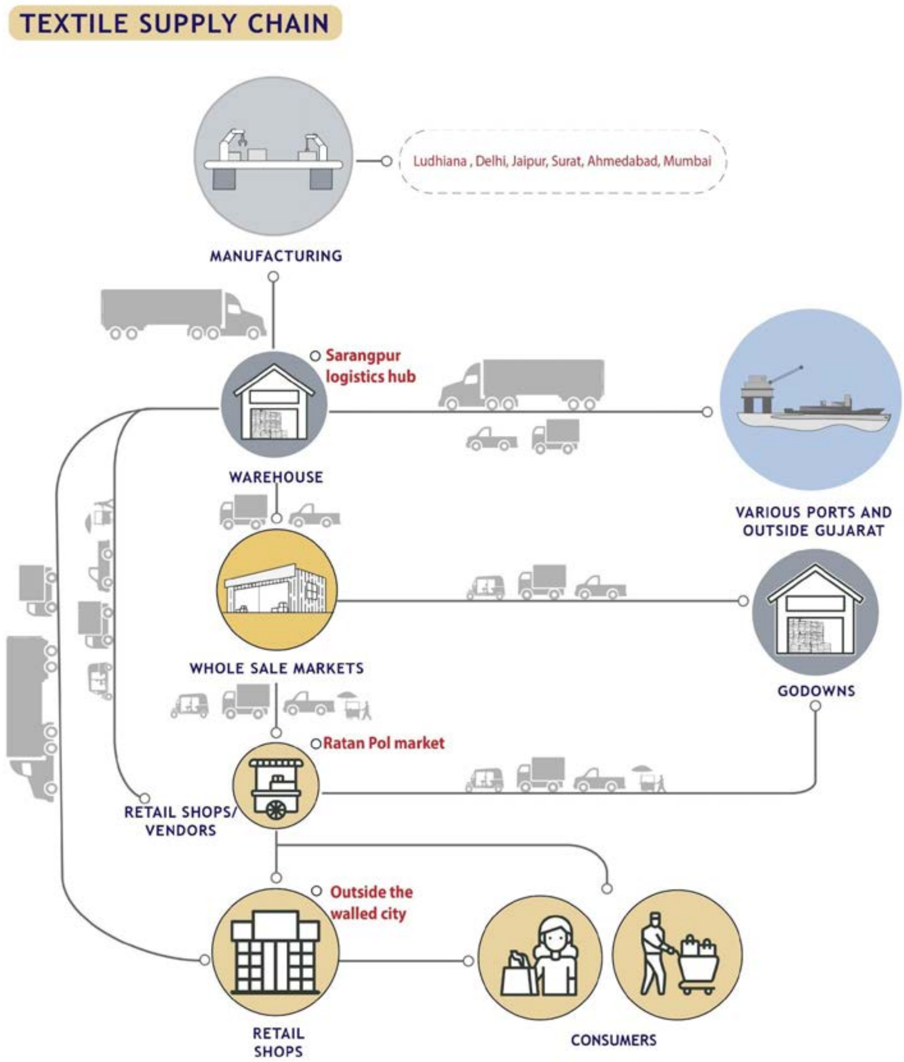
- New Cloth Market
- Safal Cloth Market
- Ratan Pol

Figure 13: Ratan Pol Market, walled city, Ahmedabad



Source: TUL Foundation

Figure 14: Textile market supply chain



Source: TUL Foundation

4.3 Perishable market

All cities have a daily requirement for perishable goods, such as fruits and vegetables. The vegetables and fruits in Ahmedabad primarily come from Kheda, Nashik, Mehsana, Nagpur and Punjab depending on the season of vegetables and fruits grown across the country. Perishables coming in from outside the city are gathered at large wholesale markets located at the periphery of the walled city, the Agricultural Produce Market Committee (APMC) market.

APMC is a statutory market committee constituted by State Governments in India to regulate the trade of agricultural commodity markets of notified agricultural, horticultural, and livestock products. It is the primary node for the delivery of perishable goods in any city in India. It was formed as per the APMC Act to ensure farmers are safeguarded from large private retailers and regulate the farm price to retail price disparity. The primary APMC market of Ahmedabad is at the periphery of the walled city. Within the walled city, six secondary markets come under the authority of the APMC.

From the APMC market, located at the periphery, the goods are primarily taken to the sub-primary APMC market, which is Kalupur Shak Market. This transport is done through HCV, MCV and LCV vehicles. From Kalupur Shak Market, the perishables go to retail markets inside and outside the walled city as well as to informal vendors (using hand carts and puller vehicles) before reaching the consumers. The movement to retail stores and informal vendors is done through LCVs, three-wheeler vehicles, and informal vending carts which are then carried around to various areas across the city.

RSI with drivers and establishment surveys were conducted at the following markets inside the study area:

- APMC Market
- Kalupur Shak Market
- Rajnagar Market

Figure 15: APMC Market, Jamalpur, walled city, Ahmedabad

Source: TUL Foundation

Figure 16: Perishable market supply chain

4.4 Electronic market

Gandhi road is one of the oldest electronics markets in walled city (refer figure 17 - Gandhi road market, walled city, Ahmedabad). The goods coming into this market are predominantly from Delhi, directly from company factories. This market caters to electric goods business owners.

Electric goods first come to Sarangpur logistics hub by HCVs and are then transported by private logistics operators. From the logistics hub, the goods are loaded in LCVs, tempos and other small freight vehicles to be taken to local warehouses on the Gandhi Road. From the local warehouse, they go to retail shops and vendors on the Gandhi Road. The goods movement happens through tempos, cycle rickshaws, and handcarts. From the retail shops at the Gandhi market, it is often transported to the consumers and retail shops outside the walled city.

During site visits, the team found that there are no fixed timings for freight movement of electric goods, and transportation is hired on a demand basis. The market is active throughout the day. People prefer to use tempos, passenger autos, cycle rickshaws, and handcarts for transportation of goods. However, larger consignments are delivered by LCVs at night through multiple trips. The general market time is observed to be 10am to 7pm.

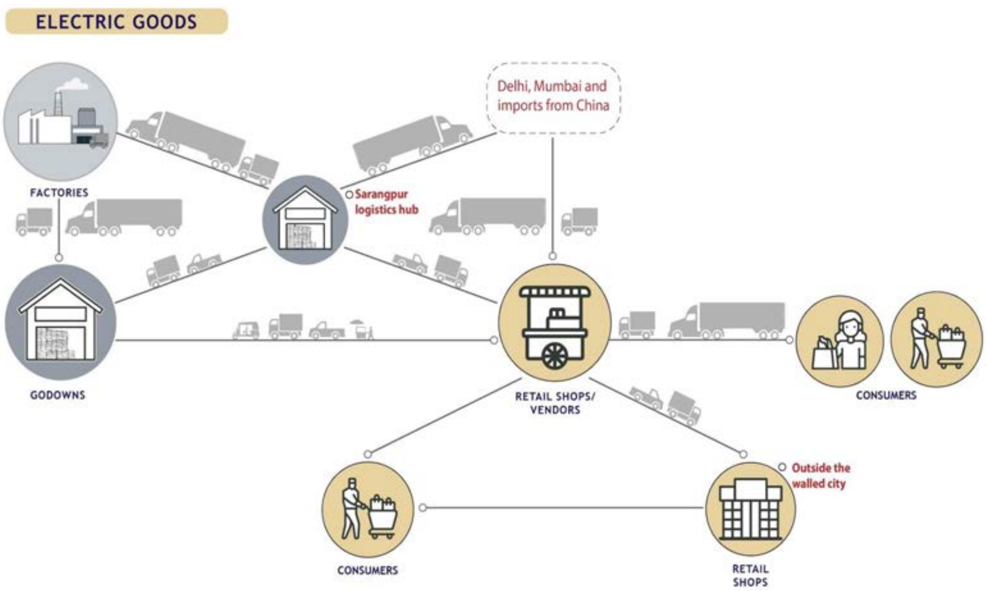
RSI with drivers and establishment surveys were conducted at the following markets inside the study area:

- Gandhi road market
- Relief road market

Figure 17: Gandhi road market, Walled City, Ahmedabad

Source: TUL Foundation

Figure 18: Electronic market supply chain



5. Methodology for Index Model Development

5.1 Methodology for Index

The methodology for the freight emission index was developed through secondary studies and expert interviews. It includes the exploration of index modelling methods for the best fit of data, identifying appropriate methods for the Ahmedabad walled city area. A hybrid index was designed with regression modelling of the vehicle characteristics (vehicle age, fuel type and engine type) as a base and a secondary correlation matrix of operational characteristics (load factor and empty running).

As identified from the literature, the following parameters have a significant effect on emissions: vehicle characteristics and operational characteristics. These parameters were used as a framework to collect data and build the index. Further, the effects of both parameters on emissions were integrated to reach an index score. The index intended these characteristics to be represented as a measure of a vehicle's emission efficiency.

The methodology is elaborated below:

1. **Data fitting for index modelling**
   - Study and experiment with various methods for creating the emission index using the identified parameters for vehicle and operational characteristics through secondary study
   - Conduct a comprehensive examination of secondary sources and engage in expert interviews to gather insights

2. **Method identification**
   - Analyse the results of the experiment process to identify effective methods for constructing the emission index
   - Evaluate each method's suitability and applicability within the study context and identify parameters for vehicle and operational characteristics

3. **Index model design**
   - Combine the methods that have been identified as appropriate to design the emission index model
   - Ensure a cohesive integration of selected methods, considering their synergies and relevance to the study objectives

5.2 Data fitting for index modelling

To choose an appropriate and valid index model, popular application-based index models were identified from the literature. Popular models explored for indexing included:

1. Principal component analysis (PCA)
2. Likert/adequacy Scale
3. Regression-based approach for modelling index.

The models are tested for fit and accuracy using the primary data collected for this study. The data fitting is as elaborated below.

1. Principal component analysis (PCA)

Principal component analysis is a statistical technique which is appropriate for large datasets. This technique is appropriate when the variables are correlated but the exact correlation is not known. PCA reduces dimensionality in a data set by combining similar variables and bringing all variables to a similar scale. The variables are transformed into principal components such that they represent the amount of variance between the variables. The PCA equation represents a linear combination of the original variables.

The first step to building a PCA-based index is to develop a correlation matrix. The matrix is developed with the following variables**: vehicle age, engine type, fuel type, number of empty trips, average overall load factor, and emission of one day** (calculated through the GLEC framework). STATA software is used to analyse the correlation matrix. The correlation between variables did not exceed 0.5. However, logically it is known that certain variables are highly correlated such as number of empty trip and average load factor. So, it was concluded that the correlation matrix is broken i.e. it does not represent the data accurately.

To test for normality in the dataset, the following techniques were used:

1. **Scatterplot:** this is a visual test for a normal distribution curve. If the sample is linearly correlated a normally distributed plot will not deviate from the curve.
2. **Multivariate normality test (Doornik-Hansen test):** the test compares the dataset's distribution with a hypothetical probable distribution (e.g.: normal distribution). The null hypothesis is that the variables are normally distributed. It provides a test statistic and p-value as an indicator of normality. The chosen level of significance for the p-value is taken at 0.05.

Through both tests, it is concluded that there is non-normality in the data. To introduce normality, the variables were transformed to their z-score values and log-values. However, both methods did not fix the issue of normality. This suggests that the data is non-linear.

Another issue in this approach is the presence of categorical variables and time-based variables which are: fuel type, engine type, level of aggregation, and time spent in congestion. While some can be transformed on an interval scale, others cannot be transformed. The variables are not innately correlated, even though they are all relevant to the emission of the vehicle, which leads to a skewed correlation matrix. Therefore, PCA based method is not appropriate for this data set.

2. Likert/adequacy scale

A Likert scale is a standard classification format for studies. It is a common approach in survey research which uses a 5 or 7-point range to capture a research question. This approach is especially useful when dealing with variables with different units and scales. It captures the varying levels of importance among different variables, based on expert opinion. The final score of the index is achieved by aggregating scores of variables as per the weight given to them.

To test this approach, a standardised five-point adequacy scale was developed for seven factors. These seven factors were divided into two dimensions: **vehicle characteristics** and **operational characteristics**.

Table 3: Likert scale for index

	Factors/Scale	Very Inadequate	Inadequate	Neutral/ optimum	Adequate	Very Adequate
Vehicle Characteristics	**Vehicle age**	10 – 15 years	7 – 9 years	5 – 6 years	3 – 4 years	2 years and less
	Engine type	BS I and II	BS 3	BS 4	BS 5	BS 6
	Fuel type	-	Diesel	Petrol	CNG	EV
Operational Characteristics	**Load factor (Textile)**	0.6 and below	0.61 to 0.8	0.81 to 1	1.1 to 1.2	1.21 & above
	Load factor (Electronics)	0.5 and below	0.51 to 0.7	0.71 to 0.9	0.91 to 1.1	1.11 & above
	Load factor (Perishable)	0.5 and below	0.51 to 0.7	0.71 to 0.9	0.91 to 1.1	1.11 & above
	No. of empty trips	4 & above	3	2	1	0
	Level of aggregation	1 shop	2 shops	3 shops	4 shops	5 and more
	Time spent in congestion	More than 20	15 to 19	10 to 14	5 to 9	Less than 5

Different methods of scoring and weighting were tried:

- **Negative range scoring** i.e. **-2, -1, 0, 1, 2**. Another method was
- **Positive range scoring** i.e. **0, 1, 2, 3, 4**. In another iteration,
- **Proportionate scoring** based on weights given to each variable i.e. **x/4, x/2.66, x/2, x/1.33, x**, where x is the weight of the indicator. For example, the weightage given to vehicle age's contribution towards emission is 20%, the scale becomes **5** (20/4), **7.5** (20/2.66), **10** (20/2), **15** (20/1.33), **20** (x).

An index score separately for each commodity, perishable, textile and electronic, was calculated.

It was found that negative range scoring was not a good fit because the total score would reflect a negative number, which cannot be used for data interpretation.

While a five-point scale theoretically made sense, it did not represent the on-ground situation accurately. All vehicles above the neutral/optimum range are equally fit to run on the road. Therefore, the scale was reduced to a three-point scale: **very inadequate, inadequate and adequate.** Positive ranged and proportionate ranged scoring were adopted to calculate the index score for each commodity.

The main challenge of this approach is assigning the exact weights for variables. The hierarchical ranking to variables is given based on secondary studies and expert opinion. However, giving an exact distribution of each parameter's contribution towards emission is not evidence-backed.

3. Regression-based index

The main aim of the index is to model relationships among variables accurately. The index should provide insights into actionable points to reduce emissions. Regression modelling gives quantifiable insights into the actual contribution of variables towards emission, providing for an explicit modelling of the relationships. Regression models can accommodate different types of variables such as numerical, categorical and time-based variables. The regression-based approach is useful when there is a clear understanding of the relationships between the variables. Through literature, it is well established that vehicle age, engine type and fuel type play a critical role in emissions.

A multivariate linear regression (MLR) analysis was used to model the relationship between the dependent variable, which is the CO value acquired from PUC certificates and the explanatory variables as vehicle age, engine type and fuel type. The null hypothesis is that a vehicle's CO produced per m^3 of smoke can be predicted by its:

1. Age (in years)
2. Engine type (BS I, BS II, BS III, BS IV, BS VI)
3. Fuel type (CNG, Petrol, Diesel)

The regression equation is as follows:

$$\widehat{VehicleCO}/m^3 = \beta_0 + \widehat{\beta_1 age_i} + \beta_2 \widehat{EngineType_i} + \beta_3 \widehat{FuelType_i}$$

Selected Index Approach

The regression-based approach provides a precise quantitative model, allowing for a clear understanding of the relationship between variables and their impact on the Freight Emission Index. Regression models are flexible and can accommodate various types of variables, making them suitable for diverse datasets. It allows for explicit modelling of relationships between variables. Coefficients from regression models can provide insights into the magnitude and direction of the impact of each variable, facilitating actionable strategies for emission reduction. **Therefore, regression-based approach was chosen to model relationships of vehicle characteristic variables.**

5.3 Primary data collection

5.3.1 Required data for the study

Through a comprehensive literature review, it has become evident that vehicle characteristics (VC) and operating characteristics (OC) play a pivotal role in influencing emissions. Diesel-fuelled vehicles stand out, contributing a significant 61% to total CO2 emissions, followed by gasoline vehicles at 37%, and CNG vehicles at 2%. Furthermore, a detailed examination of vehicle age highlights the noteworthy impact of post-2015 vehicles (0 to 5 years in the fleet of 2020), constituting 47% of total CO2 emissions (Lee Schipper, 2009). Another pertinent study, underscores the importance of vehicle operations on emissions, specifically focusing on key metrics like the load factor and the empty running rate (N. Adra, 2010). Delving into these findings emphasises the critical need to understand and address the dynamic interplay between vehicle characteristics and operational factors for effective emissions management.

Under the two main parameters of vehicle & operational characteristics, various sub-parameters are identified and discussed below:

- **Vehicle fuel type:** Fuel type is the single most contributing factor for emissions. Previous studies highlight that emissions reduce as the fuel is changed from diesel to petrol to CNG (Namita Singh, 2020). Vehicle fuel type is directly captured through driver interviews during primary RSI surveys.
- **Vehicle engine type:** Through previous laboratory studies, it is quite evident that newer engine norms have a positive impact on emission reduction. It is observed that as the engine type goes from BS1 to BS6, emissions are reduced (Apoorva Pandey, 2014). Vehicle engine type is directly captured through driver interviews during primary RSI surveys.
- **Vehicle age:** Through studies it is evident that increasing vehicle age has a negative effect on emissions. *"Vehicle's emissions start to worsen once it is seven to eight-years-old"* (Apoorva Pandey, 2014). Vehicle age is directly captured through driver interviews during primary RSI surveys.
- **Vehicle load factor:** Previous studies have established a correlation between emissions and the load factor, revealing that as a vehicle approaches full capacity, emissions tend to decrease. Through primary RSI surveys, data on maximum vehicle capacity (Tonne) & trip-wise load carried (Tonne) is captured. This helped in calculating average load factors for each vehicle (trip-wise load carried/total vehicle capacity).
- **Vehicle empty run:** Previous studies have established a direct correlation between emissions and vehicle empty runs, indicating that an increase in empty run kilometres contributes to higher vehicle emissions. As discussed earlier, load factors for all vehicle trips are derived from primary data analysis. Additionally, to pinpoint vehicle empty run kilometres, all trips with a load factor below 0.2 are categorised as empty, and the cumulative trip lengths for these instances are aggregated to determine the total empty run kilometres per day.
- **Vehicle in-congestion time:** Expert interaction & secondary studies have indicated a positive correlation between time spent in congestion & emissions. *"It is estimated that any vehicle stuck in congestion can have a 10-12% increase in emissions"* (Guttikunda, 2023). Through primary RSI surveys, actual trip durations are captured for vehicles. Further, using Google maps data, average off-peak and on-peak trip durations are cross referenced with captured trip durations to calculate trip-wise time spent in congestion (in minutes).

5.3.2 Identified primary surveys

Three types primary surveys are undertaken for data collection:

1. **Classified volume count (CVC) survey:**

A CVC survey is a method used in transportation and traffic planning to gather detailed information about the volume of vehicles travelling on a particular road or at a specific location. In a classified volume count, the vehicles are categorised or "classified" based on various characteristics such as vehicle type, size, and sometimes speed. This survey provided information on the composition of freight traffic, allowing to understand the magnitude and types of vehicles entering the walled city. This data also indicated majorly used routes inside the walled city.

2. **Road-side interviews:**

A road-side Interview (RSI) survey is a common method in transportation studies where researchers interview drivers or passengers at specific roadside locations. RSIs provided real-time information directly from vehicle users, complementing other methods like traffic counts and observations for a comprehensive understanding of transportation patterns. The survey gathered data on vehicle type, age, fuel, engine, emissions, etc, and vehicle movement (time, distance of trip) and tonnage.

3. **Survey of establishments:**

An establishment survey collecting data from physical locations where business activities, industrial operations, or services are conducted. The survey gathered information on freight transport dynamics within the chosen commodity. The survey provided key operational data, including peak and off-peak times, origin and destination of goods, types of vehicles used by establishments, tonnage flow of commodities, average monthly transport costs, supply and demand dynamics, and insights into seasonal variations in goods flow.

Table 4: Outcomes from surveys

CVC survey	RSI survey	Establishment survey
Modal split	Vehicle age	Transport demand & intensity
Vehicle routing	Trip length	Transport costs & prices
	Vehicle tonnage	Spatial structure of supply chain
	Fuel consumption	Modal split
	Carbon emissions produced by fuel source	Empty trips, under-loaded trips
	Fuel type	Load factor of vehicles
	Load factor of vehicles	Seasonal variation
	Empty trips, under-loaded trips	

5.3.3 Data collection plan

1. **Classified volume count (CVC) Survey**

CVC surveys were conducted at identified mid-blocks for the whole day (24 hours). The survey is divided into two parts, First, 24-hour videography of identified mid-blocks. Second, counting per hour vehicles crossing the mid-blocks through desktop study.

Number of CVC surveys: 7 mid-blocks

Location: At identified mid-blocks

Timing: 24 hours – one day of the week (Wednesday or Thursday)

2. **Road-side interviews**

Roadside interviews were conducted to gather data about the freight vehicle engine type, age, capacity, commodity traded, etc and data on overall trip patterns like start and end point of trip, total trip time, route taken, etc. This was conducted with drivers at identified markets during both day and night-time slots. A total of 500 RSI surveys were undertaken.

Location: At identified commodity markets

Timing: 10 am-6 pm on a weekday

3. **Establishment survey**

Establishment surveys were conducted at identified market locations during working hours (10 am-6 pm). It allowed the collection of information about the establishments such as nature of business, peak hours, magnitude of commodity coming and going, magnitude of vehicles required, types of vehicles, trip patterns, efficiency of transportation, etc. A total of 50 establishment surveys were undertaken.

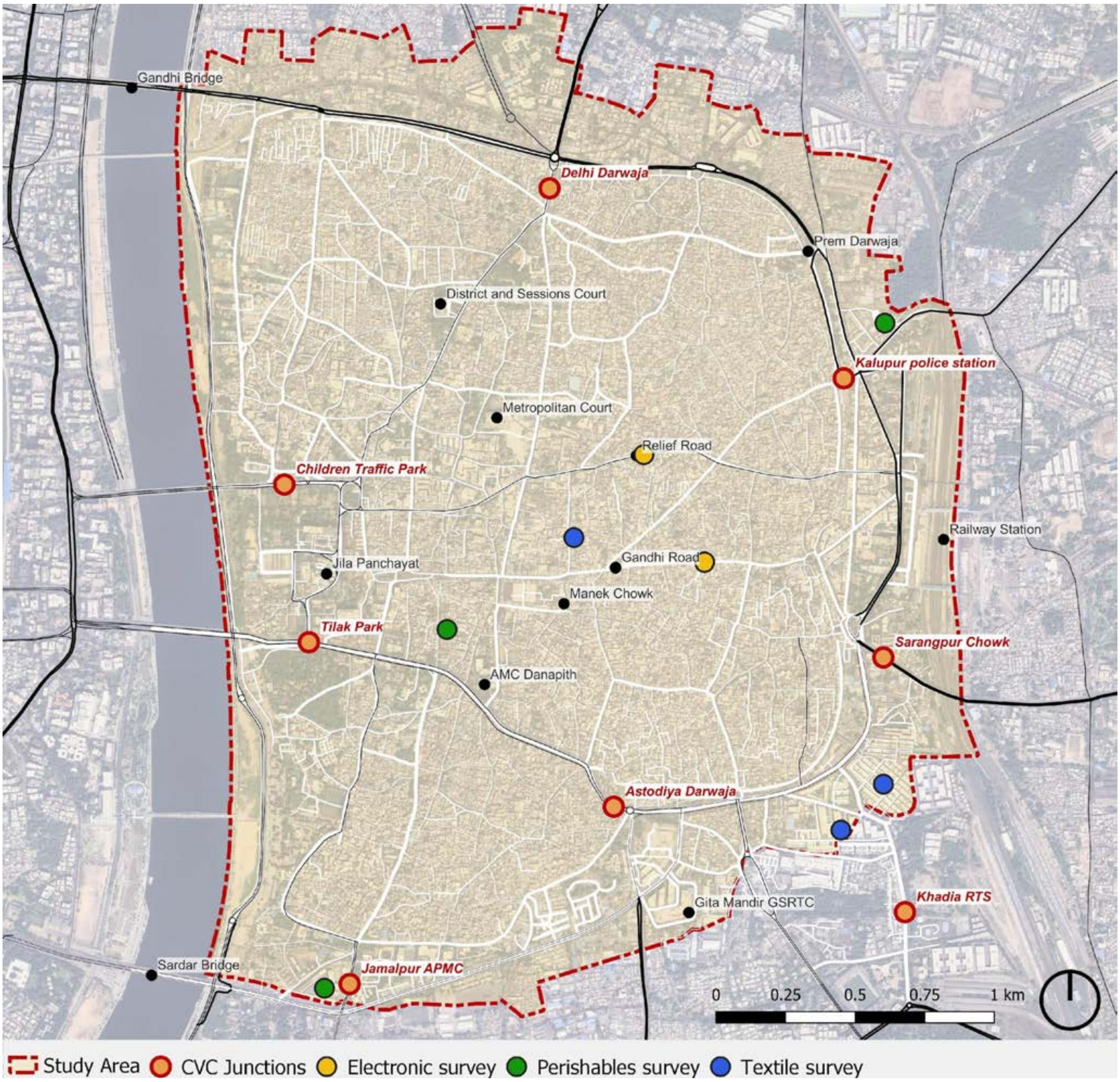
Location: At identified commodity markets

Timing: 10 am to 6 pm

Table 5: Survey market distribution

Commodity	Textile			Perishables			Electronics		Total
Market	Ratanpol market	New cloth market	Safal cloth market	APMC Jamalpur	Rajnagar market	Kalupur shak market	Relief road market	Gandhi road market	
RSI survey count	50	100	100	100	25	25	50	50	500
Establishment survey count	5	10	10	8	4	3	5	5	50

Figure 19: Identified survey locations



Source: TUL Foundation

5.4 Modelling the Freight Emission Index

5.4.1 Extraction of emission data

The exhaust emissions from vehicles comprise a range of gases, including N_2, CO_2, CO, HC, NO_x, SO_2, and PM, each with distinct adverse effects on health and the environment. Due to data constraints, the index prioritises the analysis of CO emissions from vehicles. In the Indian context, CO emission data is predominantly captured through Pollution Under Control (PUC) certificates, as revealed by findings from primary studies. The collection of PUC data is facilitated through road-side interview (RSI) surveys, providing a foundational dataset for the study. Conceptual understanding of PUC certificates is discussed below:

Pollution Under Control (PUC) Certificate

In India, a Pollution Under Control (PUC) certificate is a mandatory document that attests to the compliance of a vehicle with the prescribed emission norms. This certification holds paramount importance as it not only signifies the vehicle's adherence to pollution control standards, but also serves as a decisive indicator of its fitness in terms of emissions. The issuance of a PUC certificate is mandated by regulatory authorities and is an essential requirement for all motor vehicles. The process of obtaining a PUC certificate involves an emission test conducted at authorised testing centres.

There are two prescribed formats for PUC certificates. First, for positive ignition (PI) type engines, which support petrol and CNG. The result is provided in form of percentage of carbon emissions from total smoke emitted by the vehicle. Second, for compression ignition (CI) type engines, which support diesel and CNG. The result is provided in form of the light absorption coefficient (K value) of the total smoke emitted by the vehicle (ARAI, 2021). Sample PUC certificates are provided in the annexure.

To address the lack of precise CO emission data on PUC certificates, a conversion chart sourced from a secondary reference is used (Holubeki, 1965). This chart facilitates the conversion of the light absorption coefficient (K value) into CO density measured in mg/cum. For instance, if a vehicle records a K value of **0.61**, the resulting CO density is determined to be **96 mg/cum** Table 6. This conversion process is applied to all captured PUC certificates, converting K values into CO density. These converted values are subsequently utilised in the calculations to formulate the index model. The conversion chart has been used in multiple popular studies e.g.: Roychowdhury, A. and Chattopadhyaya, V. (2019) 'Bharat Stage VI (BS-VI) Readiness and Roadmap In India Policy Brief Centre for Science and Environment', Centre for Science and Environment [Preprint]. '13th International Conference' (2008) in Research Institute for Animal Production Nitra. Slovakia.

Table 6: K-value to CO mg/cum conversion chart

Light absorption coefficient (K value)	CO Mg/cum
0.58	91
0.61	96
0.64	101

Source: (Holubeki, 1965)

5.4.2 Index model formulation

Vehicle characteristics

The first step for the index model formulation focuses on correlating the vehicle characteristics, which include vehicle age, fuel type and engine type. As discussed in the earlier section, a regression-based approach has been used to achieve a precise quantitative model, allowing for a clear understanding of the relationship between variables and their impact on emissions. A multivariate linear regression (MLR) analysis is used to model the relationship between the dependent variable which is the CO value acquired from PUC certificates and the explanatory variables as vehicle age, engine type and fuel type Table 7.

Table 7: Regression table for Vehicle Characteristics

Variables	CO mg/m3
Age	1.678***
	-0.146
Fuel Type	9.758***
	-0.326
Engine Type	-4.400***
	-0.517
Constant	5.1345***
	-1.954
Observations	1,012
R-squared	0.806
Standard error in parenthesis	*** p<0.01, ** p<0.05, * p<0.1

The MLR models the relationship between the dependent variable, CO mg/m^3 produced by the vehicle and the explanatory variables, vehicle's age, engine type and fuel type. It signifies the increase or decrease in CO mg/m^3 for change within each variable when the other variables are kept constant.

- **Vehicle age interpretation:** Every one-year increase in vehicle age is associated with an additional **increase of 1.678 CO mg/m^3 of emissions**, holding the engine type and fuel type as constant. For example, when a vehicle's age increases from 1 year to 2 years, it is predicted to increase its emissions by an additional 1.678 CO mg/m^3, holding fuel and engine type of a vehicle constant.
- **Vehicle fuel interpretation**: Fuel is a categorical variable which is coded as CNG: 1, Petrol: 2, Diesel: 3. Every unit change in fuel type i.e. change from CNG to petrol is associated with an increase of **9.7 CO mg/m^3 of emissions,** holding age and engine type as constant.
- **Vehicle engine interpretation**: Engine type is a categorical variable which is coded as BS II: 1, BS III: 2, BS IV: 3, BS V: 4, BS VI: 5[3]. Every unit change in engine type i.e. from BS 2 to BS 3, or BS 3 to BS 4 is associated with a decrease of **4.400 CO mg/m^3,** holding vehicle fuel and age as constant.

By applying the CO density change of the regression model, all combinations of age, fuel and engine type were made and assigned the respective CO mg/m3. For example, a 10-year-old vehicle with CNG fuel and BS IV engine will have a CO emission density of 30.71 mg/cum. This CO density signifies the correlated emissions from vehicle characteristics.

$$\widehat{VehicleCO}/m^3 = \beta_0 + \beta_1\widehat{age_\iota} + \beta_2\widehat{EngineType_\iota} + \beta_3\widehat{FuelType_\iota}$$ ----- ***Equation 1***

Table 8: Combined CO density for vehicle characteristics

Vehicle age	Vehicle fuel type	Vehicle engine type	CO density (mg/cum)
23	Diesel	BS II	80.845
10	CNG	BS IV	30.715
2	Diesel	BS VI	28.007

[3] BS I engine type is not taken as none of the primary surveys with PUC consisted of BS I engine.

Load factor and empty run (operational characteristics)

The second step of the index formulation is assessing the impact of operational characteristics on emissions, i.e. the effect of load factor and empty runs. In a study conducted by Alan McKinnon and Piecyk M, titled 'Measuring and managing CO2 emissions in European chemical transport' (2010), through primary surveys the combined effect of an empty run and payload of a truck with the payload capacity of 40 tons on its carbon emission (gCO2/ton-km) was found Table 9.

For example, if a vehicle has a carrying capacity of **40 tons** and is carrying **17 tons**, and the same vehicle is running **100 km** a day and out of those **15 km** are empty runs, then the vehicle is emitting **60.8 gCO^2/ton-km** Table 9. The findings also highlight that both overloading and underloading a vehicle leads to an increase in per tonne-km emissions, emphasising that vehicle emissions are minimised when the vehicle operates near full capacity (McKinnon, 2010).

Table 9: Correlation matrix for payload and empty-run

Carbon emission factors (gCO2/tonne-km)											
Payload tonnes	Percentage of truck-kms run empty										
	0%	5%	10%	15%	20%	25%	30%	35%	40%	45%	50%
10	81.0	84.7	88.8	93.4	98.5	104.4	111.1	118.8	127.8	138.4	151.1
11	74.8	78.2	81.9	86.1	90.8	96.1	102.1	109.1	117.3	127.0	138.6
12	69.7	72.8	76.2	80.0	84.3	89.2	94.7	101.1	108.6	117.5	128.1
13	65.4	68.2	71.4	74.9	78.9	83.4	88.5	94.4	101.3	109.5	119.3
14	61.7	64.4	67.3	70.6	74.2	78.4	83.2	88.7	95.1	102.7	111.8
15	58.6	61.0	63.8	66.8	70.3	74.2	78.6	83.7	89.7	96.8	105.3
16	55.9	58.2	60.7	63.6	66.8	70.5	74.6	79.5	85.1	91.7	99.7
17	53.5	55.7	58.1	60.8	63.8	67.2	71.2	75.7	81.0	87.2	94.7
18	51.4	53.5	55.8	58.3	61.2	64.4	68.1	72.4	77.4	83.3	90.4
19	49.6	51.5	53.7	56.1	58.8	61.9	65.4	69.5	74.2	79.8	86.5
20	48.0	49.8	51.9	54.2	56.8	59.7	63.0	66.9	71.4	76.7	83.0
21	46.6	48.3	50.3	52.5	54.9	57.7	60.9	64.5	68.8	73.9	80.0
22	45.3	47.0	48.8	50.9	53.3	55.9	59.0	62.5	66.5	71.4	77.2
23	44.2	45.8	47.6	49.6	51.8	54.3	57.2	60.6	64.5	69.1	74.7
24	43.2	44.7	46.4	48.3	50.5	52.9	55.7	58.9	62.7	67.1	72.4
25	42.3	43.8	45.4	47.3	49.3	51.7	54.3	57.4	61.0	65.2	70.3
26	41.5	42.9	44.5	46.3	48.3	50.5	53.1	56.0	59.5	63.6	68.5
27	40.8	42.2	43.7	45.4	47.3	49.5	52.0	54.8	58.1	62.1	66.8
28	40.2	41.5	43.0	44.6	46.5	48.6	51.0	53.7	56.9	60.7	65.3
29	39.7	41.0	42.4	44.0	45.7	47.8	50.1	52.7	55.8	59.5	63.9

Source: (McKinnon, 2010)

Table 10: Example illustration of assigned percentage change in emissions from empty run and load factor

S no	Empty run	Load factor	Change in emissions
1	30%	0.5	-27%
2	40%	0.3	17%
3	40%	0.675	-31%
4	50%	1.8	87%
5	50%	1.8	87%
6	50%	0.25	58%

The matrix is used as the source to identify the combined effect of load factor and empty runs on emissions. The CO density from vehicle characteristics is taken as the base value for calculation, representing the vehicle in an idle state with no load and empty runs.

The process involves two steps:

1. First, the **change in CO density** is computed, and determined by the rate of change. For instance, if the rate of change is 4% and the base CO value is 5.135 mg/m3, the change is 4% of the CO value, equivalent to 0.20 mg/m3.
2. Second, the **overall effect on CO** is calculated by adding or subtracting the change in CO value from the original CO value. If the change is positive, it is added, and vice versa. For example, with a 4% rate of change and a 0.20 mg/m3 change in CO, the total effect on CO will be 5.34 mg/m3 (Equation 2) Table 11.

$$Effect\ on\ CO\ \widehat{density}\ mg/cum = \ Equation\ 1 \pm (Equation\ 1 * Rate\ of\ change)$$ ----- ***Equation 2***

Table 11: example illustrating the effect of load factor and empty run-on emissions

Vehicle characteristics CO density (mg/cum)	Empty run	Load factor	Rate of change in emissions	Change in CO density (mg/cum)	Total effect on CO density (mg/cum)
5.135	15%	0.25	4%	0.20	5.34

Congestion time (operational characteristics)

The third and final step of index formulation is the impact of a vehicle's time spent in congestion on its emissions. As per expert interviews, it was found that the maximum effect on emissions due to congestion is approximately 10%[4].

Based on trip time collected through primary surveys and Google Maps data, the duration of each vehicle's time spent in congestion is found. Proportional percentage increments, based on the calculated time spent in congestion, are then applied to the CO value associated with vehicle characteristics (Equation 3). For instance, if a vehicle demonstrates an average congestion time of **30 minutes** and has a CO value of **55 mg/cum** for vehicle characteristics, a **10% increase** is applied to encompass congestion-related emissions Table 12.

$$CO\ \widehat{mg/cum} = \ VC\ (CO\ mg/cum) * \ percentage\ increase$$ ----- ***Equation 3***

Table 12: Example illustrating impact of congestion on emissions

VC CO value (mg/cum)	Time spent in congestion (Minutes)	Effect on emission (%)	Effect on emission (mg/cum)
55	30	10%	5.5

Index scoring

To achieve the final score of the Freight Emission Index, CO values from both vehicle and operational characteristics are aggregated to establish the final CO value in mg/cum (Equation 4) Table 13. This CO value is then scaled from 1-100 score using the minimum-maximum method (Equation 5). This scoring process ensures uniformity and comparability across different commodities. To obtain an overall score for each commodity, the individual scores are aggregated to indicate a comprehensive and standardised representation of the emissions efficiency for the identified commodities. The next chapter will delve into a

[4] As per expert interviews with Dr. Sarath Guttikunda (founder/director, UrbanEmissions)

detailed breakdown of the derived index score and explore its practical applications as a decision-making tool.

$$Integrated\ \widehat{CO}\ mg/cum = Equation\ 1 + Equation\ 2 + Equation\ 3$$ ----- ***Equation 4***

$$Index\ score\ \widehat{(Out}\ of\ 100) = 100 - (\frac{Equation\ 4 - Minimum\ CO}{Maximum\ CO - Minimum\ CO} * 100)$$ ----- ***Equation 5***

Table 13: Example illustrating aggregation of the final index score

VC CO value (mg/cum)	Effect of load factor and empty runs (mg/cum)	Effect of time spent in congestion (mg/cum)	Final CO value (mg/cum)
55	25	5.5	85.5

6. Freight Emission Index Scores for Different Commodities

6.1 Emissions in the walled city

Emissions are calculated for three commodities, textile, perishables, and electronics in the walled city area based on the GLEC framework. Data on vehicle activity (total ton-km of a vehicle), and fuel efficiency (or mileage of vehicle) is gathered through driver surveys at market location. The calculated emissions are limited to the boundary of the walled city. Vehicle kilometres travelled beyond the boundary are not accounted for.

Fuel CO2 intensity factors were adopted from secondary studies. As per the World Resources Institute study titled 'India Specific Road Transport Emission Factors' (2015), the following emission factors were used:

- **Gasoline/Petrol: 2.27 kg CO2/L**
- **Diesel: 2.64 kg CO2/L**
- **CNG: 2.69 kg CO2/L**

The calculated emissions are described below.

Figure 21 shows the split of emissions of different types of vehicles in perishable markets. **Perishable market vehicles produce 5342 CO_2 g t/km daily.** Out of this LCVs are responsible for 88.3% of the total market emissions, they produce 4719 CO_2 g t/km. LCVs are responsible for a larger chunk of emissions as their vehicle activity or frequency of trips is much more as compared to larger vehicles.

Figure 20: Perishable market emissions

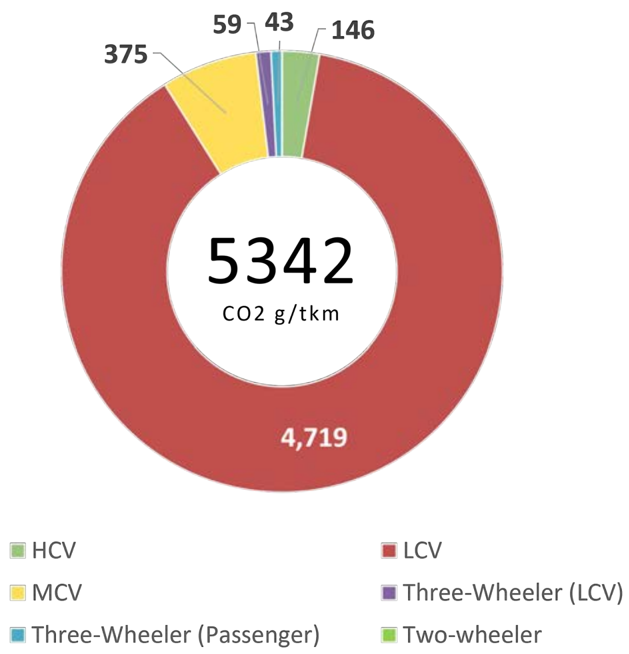


Figure 22 shows the split of emissions by different types of vehicles in the textile market. **Textile market vehicles produce 1306 CO_2 g t/km daily.** Out of this LCVs are responsible for 42% of the total market emissions and three-wheeler LCVs are responsible for 52% of total textile emissions. Together, they produce 1231 CO_2 g t/km.

Figure 21: Textile market emissions

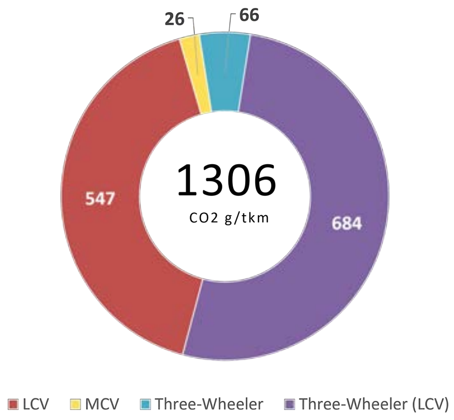
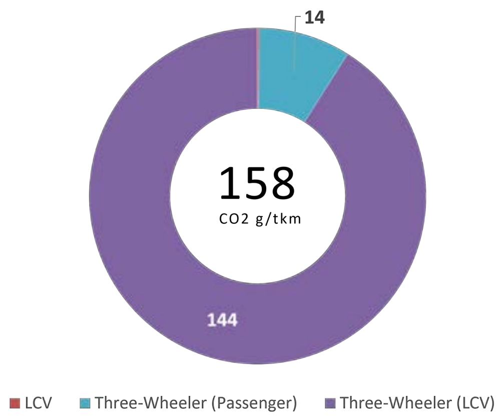


Figure 23 shows the split of emissions in electronic markets, categorised by the type of vehicles. **Electronic market vehicles produce 158 CO_2 g t/km daily.** Out of this three-wheeler LCVs are responsible for 91% of the total market emissions.

Figure 22: Electronic market emissions



While textiles have the highest market presence in the walled city, perishable market vehicles produce the most emissions as the demand for vegetables and fruits is very high compared to any other commodity. High demand means multiple daily trips by freight vehicles. The deliveries of perishable vehicles are also more spread out as they cater to all small and large local markets. The electronic market has a lower market demand as compared to textile and perishables, these freight vehicles travel 3 times a week to the market or an on-demand basis.

While the emission calculation points towards the highest emitting commodity, it does not take into account the required market demand. Market demand dictates the supply of goods in terms of the number of vehicles used to transport goods or the type of vehicle used. The demand for goods or commodities is governed by multiple factors, it is market-driven and cannot be dictated by policies and regulations. When we talk about reducing freight emissions, these reductions must consider whether the emissions are over and above the optimum for that market. The vehicle will run to keep the economy and market running.

The index intends to serve as a tool to indicate whether the market vehicles are functioning at their optimum level or if any optimisation can be made in the operational or the vehicle to reduce these emissions.

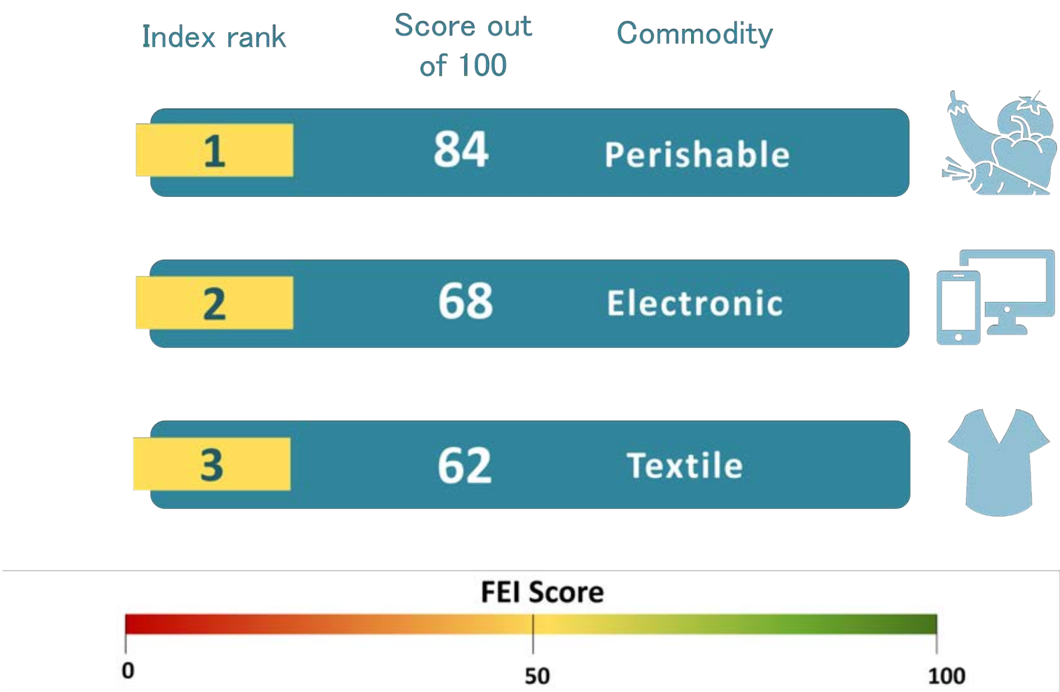
6.2 Freight Emission Index Score

The final index scores of the Freight Emission Index indicate the emission efficiency of each commodity's markets. The score does not indicate the on-ground emissions produced by the freight vehicles of that commodity, but indicates the performance of the vehicle and operational characteristics of these vehicles. The index ranges on a scale of 1 to 100. A high score, towards 100, indicates good performance of the freight vehicles in terms of their operational and vehicle characteristics. The results of the Freight Emission Index for the case of the walled city of Ahmedabad are as follows.

Perishable markets score the highest out of the three commodities, with a score of 84 out of 100. This indicates good performance in terms of vehicle and operational characteristics. The second rank is of the electronics market, with a score of 68 out of 100, and the third rank is of the textile market with a score of 62 out of 100.

Even though perishable market vehicles are the most polluting in terms of their CO_2 g emissions, since it scores the highest on the index, it is also the most emission-efficient commodity. Which means it performs well both in terms of its vehicle and operational characteristics. Textile and electronic market vehicles produce lesser emissions than perishable markets but are less emission efficient than perishables. This indicates they do not perform well in terms of their vehicles and operations. Much of the perishable goods are transported in passenger three-wheelers, which are CNG based due to government mandates, this contributes towards its goods score. For textile and electronic markets however, this is not the case, most vehicle are diesel-based three-wheeler freight vehicles.

Figure 23: Freight Emission Index scores



In the next sections, individual scores for each parameter will be looked at vehicle characteristics (fuel type, engine type and age of vehicle) and operational characteristics (load factor, number of empty runs, time spent in congestion). Each parameter is given a score out of 100 to show how the commodity performs on each parameter.

6.2.1 Vehicle characteristics score

Vehicle characteristics include the following factors:

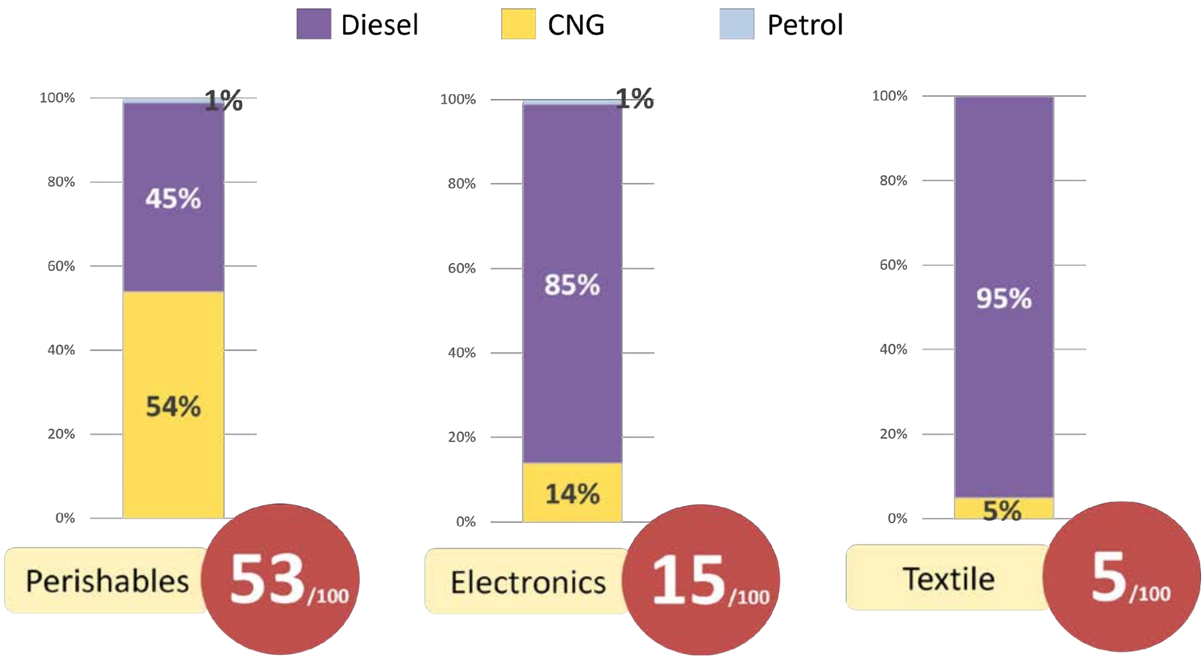
- Fuel type of vehicle
- Engine type of vehicle
- Age of vehicle

Fuel score

Diesel is the most polluting fuel as per secondary studies and as per regression analysis based on primary data, therefore the higher share of diesel-based vehicles brings down the fuel type score of the commodity.

Perishables score the highest in terms of fuel type, with 53 out of 100. As per primary surveys, 54% of the vehicles are CNG-based, 45% are diesel-based and 1% are petrol-based. The electronics market scores 15 out of 100, with 85% of vehicles being diesel-based. The textile market scores 5 out of 100, with 95% of vehicles being diesel-based.

Figure 24: Fuel-type commodity-wise score



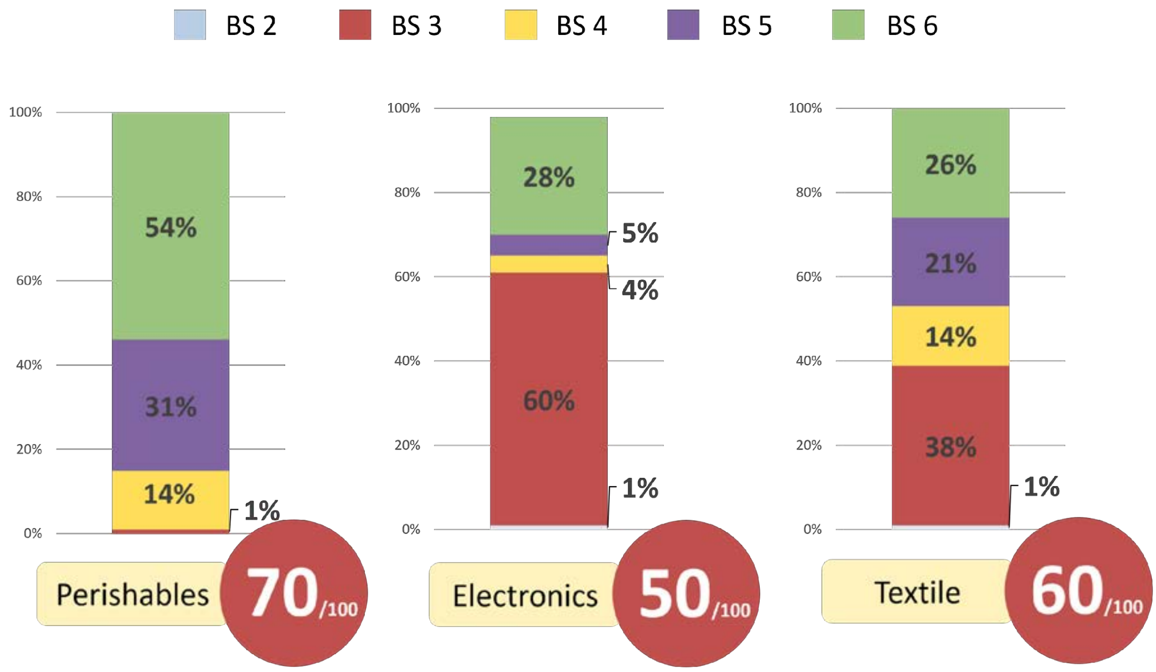
Inference: At the country level almost 90% of freight vehicles are diesel-based. However, there is a significant percentage of CNG-based vehicles in the perishable market, this is because much of the vegetables from wholesale markets are bought by roadside vegetable sellers in the city. For transporting vegetables and fruits they hire CNG-based passenger autorickshaws, in turn increasing the use share of CNG vehicles. Due to government mandates, passenger autorickshaws can only run on CNG fuel. For electronics and textile markets this is not the case. There is a major use of diesel-based 3-wheeler light commercial vehicles (LCVs). These vehicles engage only in freight activity and have a requirement of higher payload capacity, therefore are diesel-based.

Engine score

The engine type is indicative of improvement in vehicle technology. Older vehicle technologies such as BS 1, 2, and 3 are considered more polluting than newer vehicle technologies, such as BS 4, 5, and 6. Based on the impact on emission as identified by the regression analysis, older to newer engine types are given scores as per their impact on emission. The higher score is indicative of newer vehicle technology.

Perishables score the highest in terms of engine type, with 70 out of 100. As per primary surveys, BS 5 engine type vehicles are 31%, and BS 6 type are 54%. Textile scores the second highest, with 50 out of 100. The engine type composition is: BS 3 type vehicles are 38%, BS 4 type are 14%, BS 5 type are 21% and BS 6 are 26%. Electronics is the third-ranked, scoring 50 out of 100. The engine type composition is as follows: BS 2 type is 1%, BS 3 type is 60%, BS 4 type is 4%, BS 5 are 5%, and BS 6 type is 28%.

Figure 25: Engine-type commodity-wise score



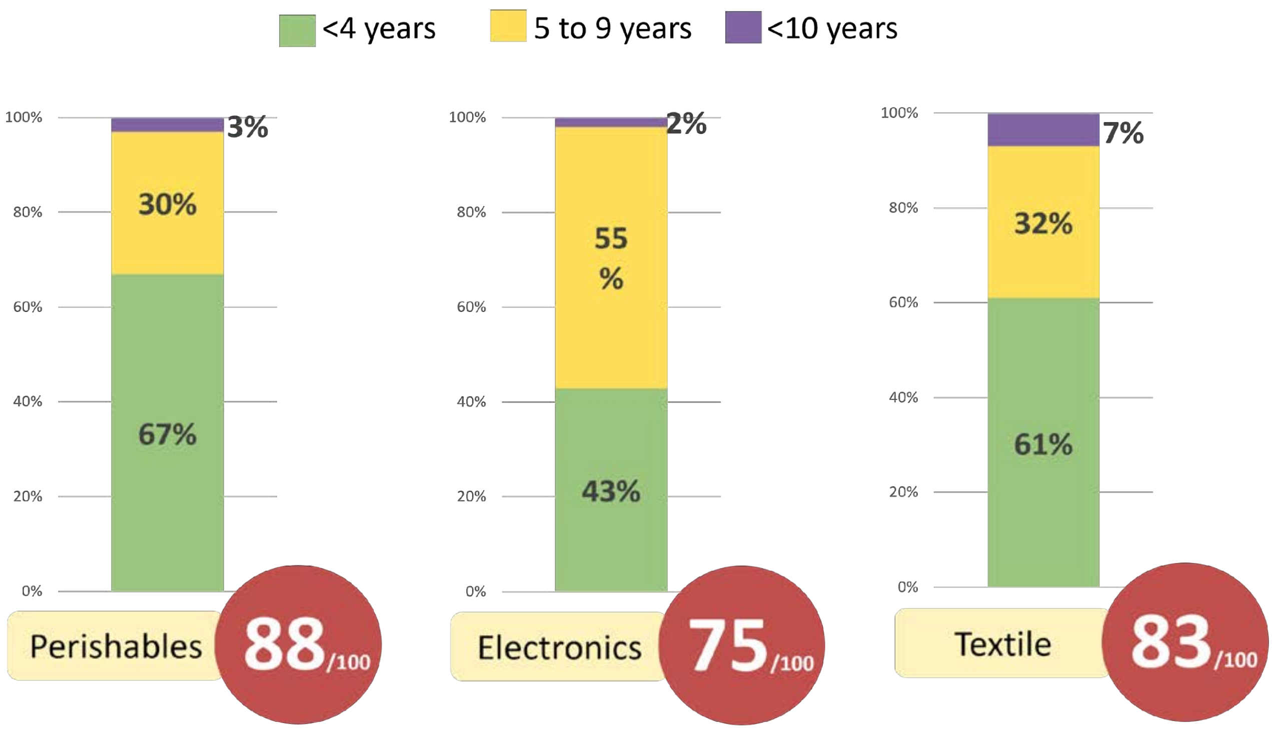
Inferences: There is an evident use of newer engine types in perishable markets. One reason is that the majority of the freight, which is vegetables and fruits, is transported directly from the farmers and comprises daily trips as there is a high demand for fruits and vegetables in the city. The vehicles take long-haul trips and travel daily. Newer vehicles are more cost-effective in terms of vehicle maintenance costs, especially for long-haul travel. For electronic and textile markets, the vehicles take short-haul trips and frequent as per demand. Therefore, the use of older engine types is prominent as the cost of vehicle maintenance will not be as high for these trips.

Age score

The age of the vehicle is also indicative of the vehicle's technology. In India, the vehicle scrappage policy mandates the discontinuation of vehicles above the age of 10. Many studies point towards a correlation between an increase in age and drop in vehicle mileage, which contributes to higher emissions. This drop in mileage is exponential beyond the age of 4-5 years (Stefano Caserini, 2013) (Theodoros Zachariadis, 2001).

Perishables score the highest, with 88 out of 100. 67% of the vehicles are below the age of 4 years and 30% of the vehicles are between 5 to 9 years. Only 3% of vehicles are above the age of 10 years. Textiles scores second highest, with 83 out of 100, 61% of the vehicles are below the age of 4 years, 32% are between the ages of 5 to 9 years and 7% are above the age of 10.

Figure 26: Age commodity-wise score



Inference: Overall, all commodity market indicates a considerable use of newer vehicles as scrappage policy mandates 10 years of operational age. Secondly, older vehicles have higher maintenance costs.

6.2.2 Operational characteristics score

Operational characteristics include the following factors:

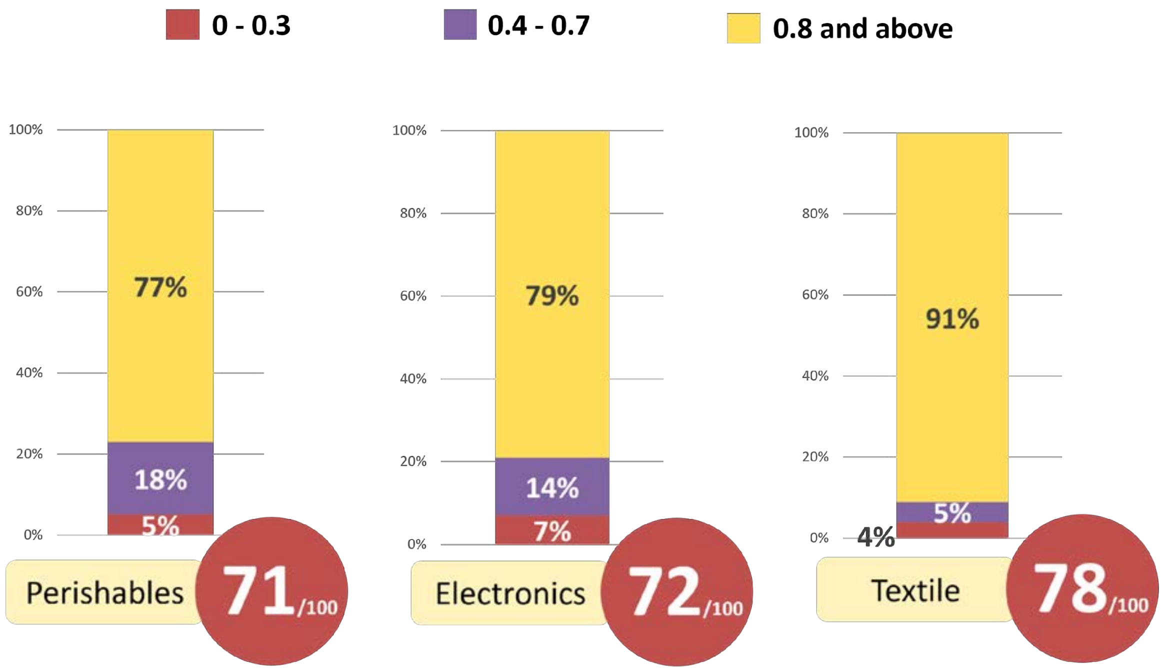
- Load factor of vehicle
- Percentage of empty runs taken out of the entire trip
- Time spent by vehicle in congestion

Load factor score

The load factor of a vehicle is the ratio of its carrying capacity and the load it is carrying. It is indicative of the vehicle's productivity and utilisation. Load factor affects emissions in a macro-view. A lower load factor would mean either more trips are taken by the vehicle to transport the goods or that more vehicles are required to transport the same goods.

Textiles scores the highest, with 78 out of 100, 91% of the vehicles carry up to 80% of their payload capacity. Electronics and perishables score very closely with 72 and 71 out of 100 respectively. 79% of electronic market vehicles and 77% of perishable market vehicles carry up to 80% of their payload capacity.

Figure 27: Load-factor commodity-wise scores



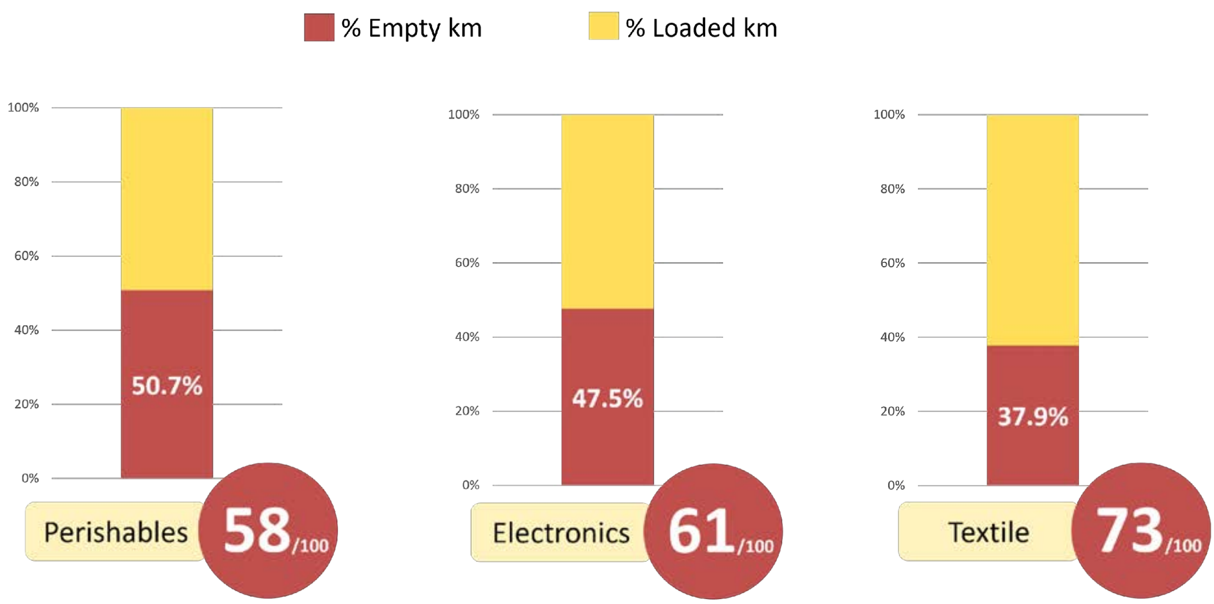
Inference: All commodities score well in terms of the vehicle load factor. During stakeholder interaction, it was found that the vehicles are owned by the individual drivers and the drivers are paid either based on the weight of the commodity on a per-parcel basis. Since the load factor is highly interlinked with the profitability of the drivers and businesses there is an optimum utilisation of the load factor.

Empty run score

Underloaded or empty trips are also an important indicator of vehicle utilisation. The higher number of empty trips indicates low vehicle utilisation, low operational efficiency and more emissions.

Textile scores the highest, with 73 out of 100. 38% of the total km travelled by these market vehicles are empty runs. Electronic ranks second, with 61 out of 100, 47% of the total km travelled are empty runs. Perishables ranks third, with 58 out of 100, 50.7% of the total km travelled are empty runs.

Figure 28: Empty-run commodity-wise score



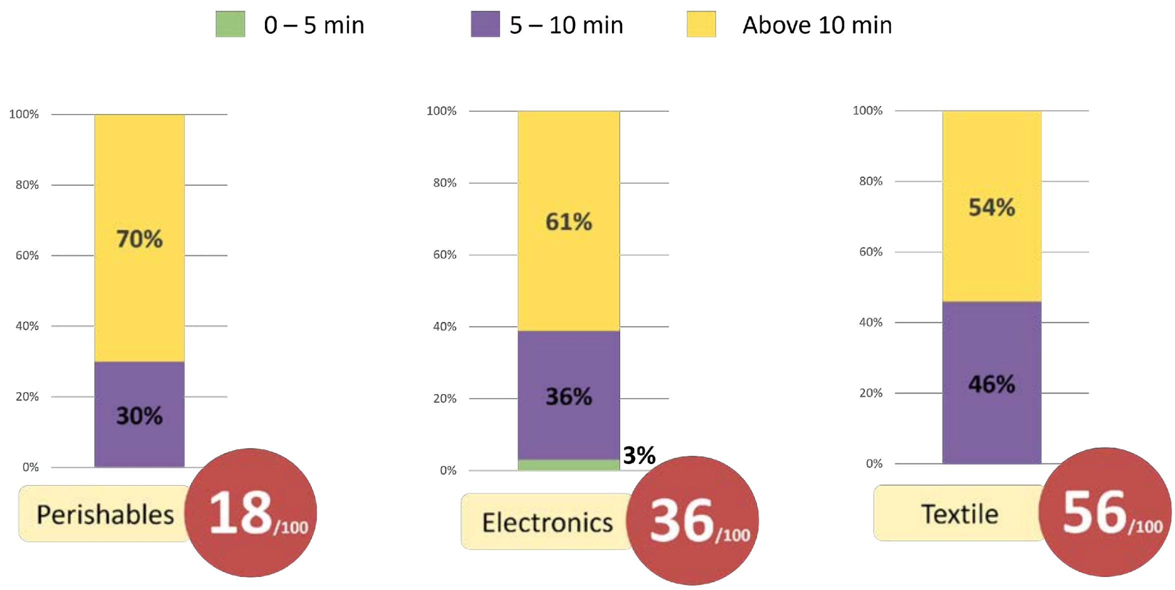
Inference: All three commodities show a similar range of empty runs, between 40 to 50%. The major reason is that vehicles after delivering goods almost always go back empty. This means out of every 2 trips taken by a freight vehicle, at least one goes empty.

Congestion score

Time spent in congestion is indicative of the time spent by the vehicle idling. When vehicles are left turned on in idling, they add to the on-road emissions. While some vehicle drivers may turn off their vehicles in long congestion/idle times, since the study area here is limited, it is assumed the vehicles in congestion keep their vehicles on, therefore adding on to idling emissions.

Textile score the highest, with 56 out of 100. 46% of vehicles spend 5 to 10 minutes in congestion, and 54% of vehicles spend above 10 minutes in congestion. Electronic scores are second highest, with 36 out of 100. 3% of the vehicles spend 0 to 5 minutes in congestion, 36% spend 5 to 10 minutes and 61% spend above 10 minutes. Perishable ranks third with 18 out of 100. 30% of vehicles spend 5–10 minutes in congestion, and 70% of vehicles spend above 10 mins in congestion.

Figure 29: Congestion commodity-wise score



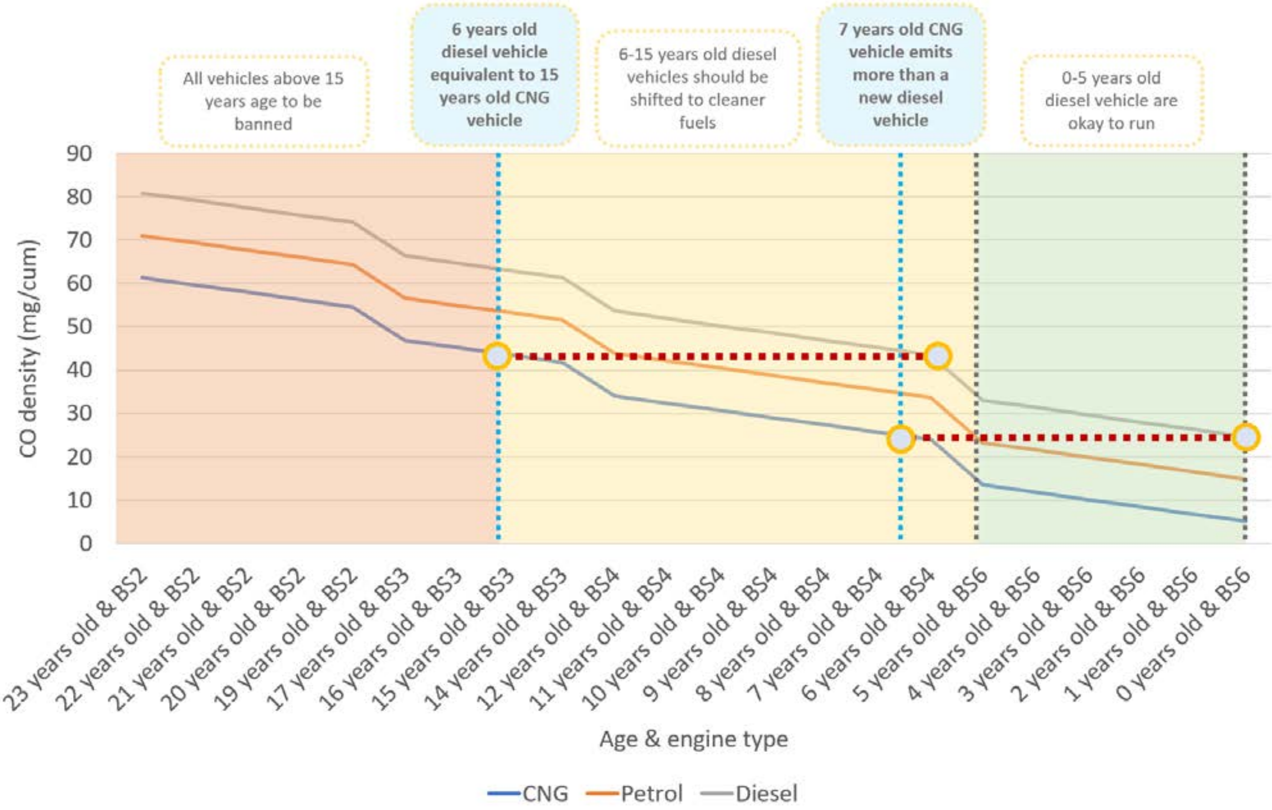
Inference: While the study area is small and the distances are not that long, there is a higher presence of narrow roads and the RoWs are limited, so all freight vehicles spend a certain amount of time in congestion which adds to the idling emissions. However, since the walled city area cannot be changed structurally, the congestion time cannot be further optimised.

6.3 Use of index for acceptable on-road vehicles

The index provides insights into emissions across various fuel types, considering different vehicle ages and engine types.

- **6-year-old BS4 diesel** vehicle exhibits emissions comparable to a **15-year-old BS3 CNG** vehicle. This analysis suggests that running BS6 diesel vehicles up to 5 years of age is acceptable due to lower emissions.
- Emissions significantly escalate in diesel vehicles older than 5 years, particularly those with BS4 and BS3 engines, indicating a need to transition such vehicles to cleaner fuel types.
- A restriction is recommended for vehicles aged 15 years and above, advocating for their prohibition and scrappage due to high emissions across the board.

Figure 30: Comparison of vehicle emissions across engine type, age and fuel



7. Index as a decision-making tool

7.1 Exploring index features and useability

The FEI provides information regarding the impact of vehicle characteristics and operational characteristics on emissions. The vehicle characteristics include engine type, age, and fuel type and the operational characteristics include load factor, dead kilometres, and time spent in congestion. The index provides commodity-specific individual contributions of each of the above-listed parameters to the overall scores. This feature enables the use of this index to set emission reduction targets and identify strategies specific to the contributing parameters. The index is converted into a dashboard to provide an understanding of the real-time impact on emissions for any strategy identified through the use of the index.

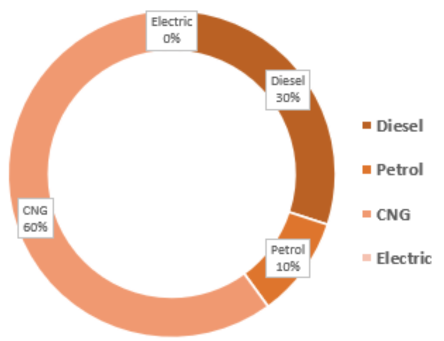
The section below explains mitigation strategies for 'electronics' commodities through the use of the FEI dashboard. The study selected electronics as a commodity for developing mitigation strategies as it has the lowest score amongst the three selected commodities. The snapshot of the dashboard shown in the figure below presents the existing scores for perishable and electronics. The dashboard also highlights scores for vehicle and operational characteristics.

Figure 31: Existing score of perishable and electronics

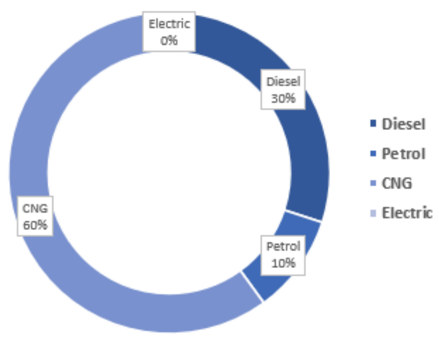
Existing Freight Emission Index

Perishables		Electronics	
77		67	
Vehicle Characteristics	Operation Characteristics	Vehicle Characteristics	Operation Characteristics
72	86	59	77
Age	Load factor	Age	Load factor
73	74	63	67
Fuel type	Empty runs	Fuel Type	Empty runs
65	72	48	70
Engine Type	Time spent in congestion	Engine Type	Time spent in congestion
60	80	48	65

Fuel type composition



Fuel type composition



Note: All values are scores out of 100

The index, as explained in earlier chapters highlights the level of efficiency in freight emissions. A higher score represents better efficiency and lower emissions for a commodity transferred per km. The tool can be used for decision-making to first establish an emission reduction target that could be reflected as improving the overall index score. The section takes an example of improving the score to 80 to highlight the usability of the index for decision-making and developing strategies.

The table below outlines a representative data set from the collected primary data for the transport of electronics commodities. The distribution by different parameters such as engine, fuel type, load factor and empty run is representative of the total data collected for the study.

Table 14: Representative data of current scenario

S no	Age (years)	Engine	Fuel type	Load factor	Empty run percentage	Average Time spent in congestion (minutes)
1	8	BS4	Diesel	0.5	50%	5
2	9	BS3	CNG	0.3	40%	25
3	8	BS4	Diesel	0.7	35%	5
4	15	BS2	CNG	0.2	20%	5
5	6	BS4	Diesel	0.4	30%	7
6	20	BS2	Diesel	0.9	30%	12
7	1	BS6	Electric	0.3	40%	3
8	8	BS4	Petrol	0.9	45%	15
9	4	BS6	CNG	1.2	10%	20
10	7	BS4	Diesel	0.8	50%	25

The table below now highlights the changes done in the existing parameters to achieve an index score of 80. The changes are highlighted in yellow and listed below.

- Vehicles with an age of more than 8 years and fuel type as diesel were converted to CNG.
- Vehicles with age more than 15 (above scrappage age) were converted to electric.
- Vehicles carrying load capacity less than the average load factor (0.6) were improved to match the average optimum load factor of 0.6.
- Vehicles with empty runs more than the average empty run of 35% were reduced to 35%.
- No changes were made to time spent in congestion as the time spent in congestion is not high

Table 15: Representative data for the proposed scenario

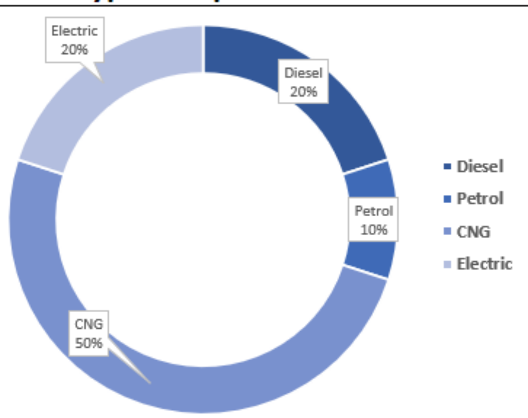
S no	Age (years)	Engine	Fuel type	Load factor	Empty run percentage	Average Time spent in congestion (minutes)
1	8	BS4	CNG	0.6	35%	5
2	9	BS3	CNG	0.6	35%	25

3	8	BS4	CNG	0.7	35%	5
4	15	BS2	CNG	0.6	20%	5
5	6	BS4	Diesel	0.6	30%	7
6	20	BS2	Electric	0.9	30%	12
7	1	BS6	Electric	0.6	35%	3
8	8	BS4	Petrol	0.9	35%	15
9	4	BS6	CNG	1.2	10%	20
10	7	BS4	Diesel	0.8	35%	25

Based on the proposed changes, the revised index score for electrical commodity is 80. The same is reflected in the figure below.

Figure 32: Revised index score with proposed strategies

Electronics	
80	
Vehicle Characteristics	Operation Characteristics
73	74
Age	Load factor
63	86
Fuel Type	Empty runs
80	73
Engine Type	Time spent in congestion
48	65
Estimated Capital Cost (in Rs.) (in Crore)	
5	
Fuel type composition	



7.2 Emission reduction strategies for electronics

The index is a numeric tool that can be used to establish emission reduction targets. A decision maker can test multiple combinations of altering the freight scenario and parameters to achieve the desired result. The section below explains the multi-pronged strategies required in policy intervention, regulatory framework, technology adoption, and design innovation to achieve the desired reduction in emissions. The key strategies identified to reduce emissions and improve efficiency in the freight movement of electronic commodities are listed below.

- **Revision in vehicle scrappage policy**: The index and emission calculations highlight that the age of the vehicle has a significant impact on emissions. Vehicle emissions increase with a higher rate per increase in age after 7 years of operations. This could be due to poor maintenance, wear and tear, and old engine type. Secondly, the impact of age is co-related to the fuel type. The current scrappage policy in India highlights the maximum age limit for all vehicles as 15 years. The findings of the study suggest an amendment of the vehicle scrappage age to 10 years for diesel and CNG vehicles.
- **Incentive to transition to cleaner fuel**: Transitioning to cleaner fuel, such as electricity and hydrogen, is the default solution for curbing emissions completely. However, the transition is cost and resource-intensive, requiring support charging infrastructure, production capacity, and price competitiveness with existing freight vehicle models. The transition is a long-term solution and will be gradual, especially in the case of developing countries. The governing authorities need to prioritise transition in phases, such that the highest polluting trips are converted first. In the case of the study examples, the strategy should nudge the conversion of vehicles older than 12 years to electric vehicles. This nudge would require incentives in the form of subsidies and strict scrappage age enforcement. The index proves to be useful in identifying the category of vehicle for transition. Hence, allowing decision-makers to implement the most effective strategies.
- **Design innovation to improve load factor**: The current scenario highlights that vehicles are underloaded for most trips. This is due to a lack of aggregate orders as distribution is fragmented for electronics and products are supplied to individual retail/wholesale stores. Secondly, electronics are sensitive to damage and over-loading as appliances such as fridges, televisions, and ovens, cannot be stacked. The current open roof and single-floor design limits the load-carrying capacity of vehicles. There is a need for design innovation that can allow material stacking and loading that allows to improve the load factor of freight vehicles.
- **Market aggregation to reduce empty runs**: The current electronics market is spatially fragmented. Deliveries are scheduled for individual retail or wholesale shops. This results in the underutilisation of freight vehicles and increases empty runs. The fabric and the building of the market in the walled city of Ahmedabad restrict the possibility of market aggregation. The strategy could be implemented in a context where reallocation of markets is possible.
- **Technological solutions to reduce empty runs**: The current deliveries of electronic commodities are scheduled for individual retail or wholesale establishments. This often leads to underutilisation of load capacity due to a smaller quantum of product or empty runs. Application-based solutions that allow delivery booking for multiple deliveries within the same area, route optimisation, and dead run reduction will aid in reducing the empty runs to an optimum of 35%. The application could be developed by the governing authority or in partnership with a private player. The algorithm should incentivise and aid in cost saving for aggregating trips and reducing empty runs.

8. Conclusion

The research aimed at developing a scalable methodology to prepare a Freight Emissions Index for walled cities; identify specific commodities that need to be targeted to lower the extent and impact of emissions in walled cities; and assist decision-makers in using the Freight Emissions Index to develop commodity-specific strategies to reduce freight emissions. In this aspect, the methodology developed is outlined in a step-by-step procedure for other cities to adopt. The data set identified is universal and consistent. It is available in all other cities in India. The primary data collection method and the sampling method is minimal and resource-efficient. The study also provides a template that can be used by other cities to collect similar data.

The index was developed for three key commodities identified through a selection framework based on market presence and relevance. The study outlines strategies and interventions specific to electronic commodities. However, similar strategies will benefit the other two commodities. Lastly, the index was converted into an interactive dashboard that can be used as a decision-making tool. The dashboard is specific to the case study. The structure and framework adopted can be replicated by other cities by generating city-specific data to review emission scores for individual parameters in the same template. The knowledge dissemination workshops aimed at testing the usability of FEI as a decision-making tool. The session led to the identification of strategies and discussion on the implementation of these strategies.

The mitigation and reduction strategies developed as part of the study highlight the need for a multi-pronged approach that encompasses policy initiative, regulatory framework, enforcement, design innovation, and technological applications. The study aimed to develop a method to set emission reduction targets and empirically test the impact of strategies on emission levels. The findings highlight that fuel type and vehicle age have the highest impact on the efficiency of freight emission. However, emission reduction can be achieved by improving the operational efficiency of freight movement.

9. Way forward

The study focused on calculating carbon emissions and the index reflects carbon emissions from freight vehicles. Carbon emissions are prime contributors to GHG gas emissions. However, there is a need to understand the implications and impact of other GHG gases including NOx and PM2.5. The study was limited to carbon emissions as the Pollution Control Certificates (PUC) only provide information relevant to extracting carbon emissions. Secondly, the calculations relied on the use of emission data from PUC that provides information on emissions in idling conditions. The impact of operational performance was loaded onto the idling condition emissions. However, there is a need for a study that captures real-time emissions of a large sample size to provide a more accurate understanding of emissions on the ground. Lastly, the study assessed three commodities. Future studies could look at a comprehensive assessment of all commodities and develop standards that could be replicable to other cities in India.

10. Knowledge dissemination workshop and webinar

With the development of the emission index, TUL Foundation, funded by HVT and UK-Aid hosted a knowledge dissemination workshop on the emission index for the walled city of Ahmedabad. The motive of the workshop was to understand the perspective of the various stakeholders in the city that can help impose various strategies and understand the benefits of reducing emissions from freight vehicles.

The workshop had a total participation of 70 people, including members from the Municipal Corporation of Ahmedabad, IIM Ahmedabad, industry experts, academia, and media. The panel discussion along with prominent personnel in the field of logistics, environment and supply chain management with Dr. Debjit Roy, Dr. Neha Upadhyay and Mr. Amit Bhatt gave insights into the challenges and opportunities in implementing various strategies to reduce emissions.

10.1 Session 1 – Study background and findings

TUL Foundation discussed the study's findings and presented a roadmap to mitigate freight emissions. The team showed the various factors that were used to prepare the index and the methodology used to prepare the index.

10.2 Session 2 – Hands-on exercise

The hands-on exercise was conducted through an interactive dashboard of the emission index helped the decision makers and the workshop participants to understand the impact of the various parameters on reducing emissions. It also helped participants think about tangible strategies that can be used to adapt to the reduction of emissions. The participants were forced to think as decision-makers in the city to provide implementation strategies.

10.3 Session 3 – Panel discussion

The panel discussion comprised industry representatives and academic experts in the field of logistics and supply chain management from the Indian Institute of Management- Ahmedabad (IIM-A), Ahmedabad Municipal Corporation (AMC) representative and electrification expert from the International Council of Clean Transportation (ICCT). The speakers highlighted some of the key challenges and strategies that can be implemented in the walled city.

Dr Neha Upadhyay, an environmental engineer from AMC, mentioned the role of central and state government bodies in adding to the vehicle scraping policy and improving them to reduce freight emissions. She also elaborated on the importance of public awareness and campaigns regarding vehicle emissions.

Dr Debjit Roy, from IIM-A, spoke about the market aggregation and disaggregation challenges. He also spoke about the supply chain mandates that can be implemented and how the dead runs, and the loads, are not in the hands of the experts but depend largely on the nature of the market.

Mr. Amit Bhatt from ICCT having worked on various national electrification policies spoke about the challenges of a BS4 vehicle that is 4-5 years old still emitting more GHG than a BS6 engine type vehicle and how such vehicles hardly move out of the system. The speaker also emphasised the price we are willing to pay for public health as the vehicle tailpipe emissions on the ground are found to be 60-70 times the lab-based emissions.

10.4 Key findings

- In addition to the vehicle scrapping mandates at the city and central level, incentives to ensure scrappage of inefficient vehicles.
- The importance of market aggregation and its role in reducing vehicle emissions.

- Importance of driver training networks for the operators of freight vehicles to better improve the quality of air in the city.
- The long-term effect of older engine types on freight emissions as vehicles hardly move out of the system.
- Scaling up of electrification in a large way through interesting policies and financial incentives for electrification versus public and private charging infrastructure.
- Communication and outreach on improving vehicle conditions to improve the efficiency of vehicles.

○ Appendix A: Survey questionnaire

1. Road Side Interview Form

Section A – Basic Information

1) **Survey Number: ____**

2) **Survey Location**
   - APMC Jamalpur
   - Rajnagar Vegetable Market
   - Kalupur Shak Market
   - Relief road Electronic Market
   - Gandhi road Electronic Market
   - Ratanpol Cloth Market
   - New Cloth market
   - Safal Cloth Market

3) **Mention products being transported**
   - Perishables
   - Textile
   - Electronics
   - Other

Section B – Vehicle Information

4) **Mention the type of vehicle**
   - Two-wheeler (if used for freight)
   - Three-Wheeler (if used for freight)
   - Light Commercial Vehicle (LCV up to 8 Ton)
   - Medium Commercial Vehicle (MCV 8 to 16 Ton)
   - Heavy Commercial Vehicle (HCV 16 tons and above)

5) **Mention vehicle manufacturer**
   - TATA
   - Mahindra
   - Ashok Leyland
   - TVS
   - Hero
   - Vikram
   - Atul Shakti
   - Bajaj
   - Honda

6) **Mention vehicle fuel type**
   - Petrol
   - Diesel

- CNG
- Electric

7) **Provide the mileage of the vehicle: ________**

8) **Provide the current vehicle occupancy** *(to be observed by surveyor)*
   - 20% or below
   - 20% to 40%
   - 40% to 60%
   - 60% to 80%
   - 80% to 90%
   - 90% and above

9) **Provide the total vehicle capacity (in tonnes): _____________**

10) **Mention the current weight of commodity (tonne): _____________**

Section C – Information from PUC Certificates

11) **vehicle registration year: __________**

12) **Engine type:**
   - BS I
   - BS II
   - BS III
   - BS IV
   - BS V
   - BS VI

13) **Measured CO emission: ____**

14) **Date of PUC: __________**

Section D – Other Information

15) **How many shops did you deliver goods to in this trip?**

16) **Mention your parking locations inside walled city yesterday**

17) **Mention the average duration of parking/halt (in hours)**

18) **What are your average goods loading and unloading time (In minutes)?**

Section E – Trip Diary

19) **Trip number: _________**

20) Mention location of origin of trip (refer to map): ______________

21) Mention the location of the end destination of the trip (refer to map)

22) Weight of good in vehicle during trip: _________

23) Trip duration (in minutes): __________

2. Establishment Survey Form

1) Type of Commodity

- Textile
- Perishables
- Electronic

2) Market name

- APMC Jamalpur
- Rajnagar Vegetable Market
- Kalupur Shak Market
- Relief road Electronic Market
- Gandhi road Electronic Market
- Ratanpol Cloth Market
- New Cloth market
- Safal Cloth Market

3) What is the type of establishment?

- Distributor
- Sub-market/retail

4) Mention specific commodities handled: __________

5) Mention the number of vehicles that come to your establishment daily.

6) Mention the number of vehicles that come to your establishment in a week.

7) Mention the vehicle information (type of vehicle as per weight)

Type of vehicle	No. of vehicles of this type yesterday	Avg. tonne loaded yesterday
Three-wheeler		
LCV		
MCV		
HCV		

8) What are the origin for the goods in your shop?

9) What is the destination for goods in your shop?

10) What is the peak time for arrivals?

11) What the peak time for dispatches?

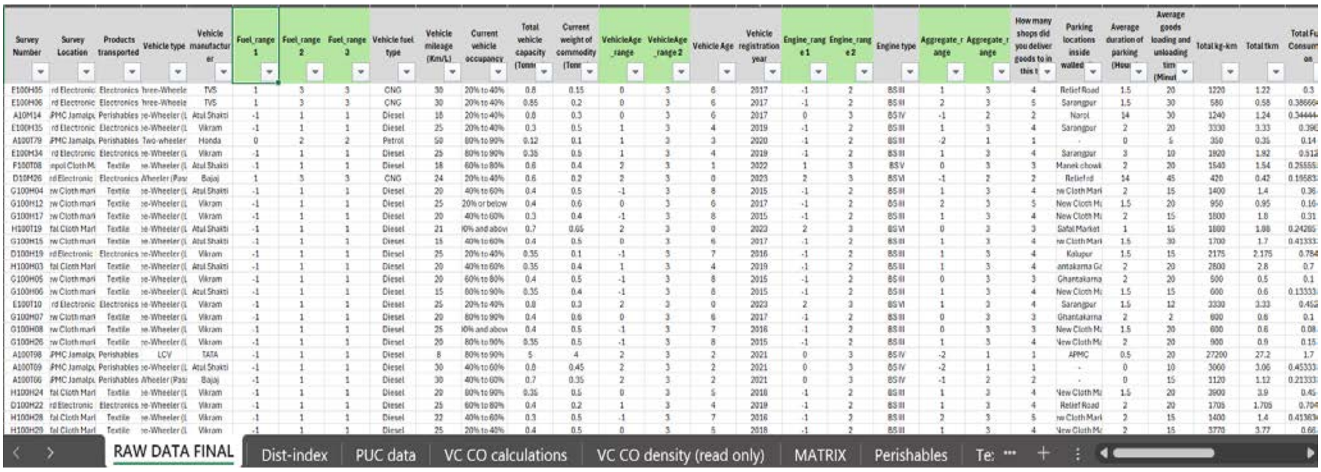
12) Is there any seasonality in commodity's demand?

13) If yes, then, which months have more demand?

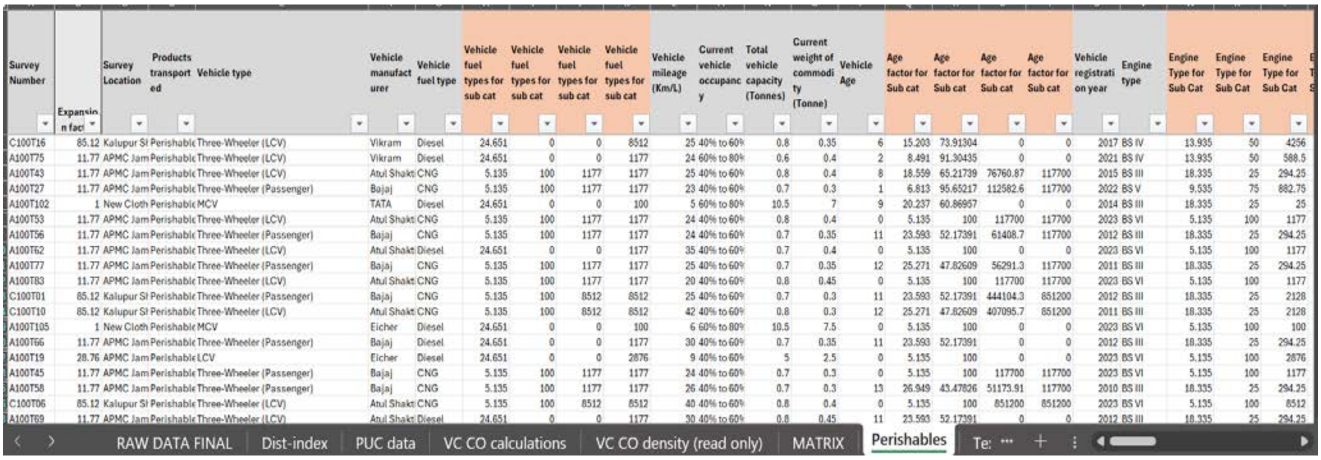
14) How much is the variation (in tonne per day)?

○ Appendix B: Snapshot of data

1. RSI DATA



Survey Number	Survey Location	Products transported	Vehicle type	Vehicle manufacturer	Fuel_range 1	Fuel_range 2	Fuel_range 3	Vehicle fuel type	Vehicle mileage (Km/L)	Current vehicle occupancy	Total vehicle capacity (Tonn	Current weight of commodity (Tonn	VehicleAge_range	VehicleAge_range 2	Vehicle Age	Vehicle registration year	Engine_range 1	Engine_range 2	Engine type	Aggregate_range	Aggregate_range	How many shops did you deliver goods to in this t	Parking locations inside walled	Average duration of parking (Hou	Average goods loading and unloading tim (Minut	Total kg-km	Total tkm	Total Fu Consum on
E100H05	rd Electronic	Electronics	hree-Wheele	TVS	1	3	3	CNG	30	20% to 40%	0.8	0.15	0	3	6	2017	-1	2	BS III	1	3	4	Relief Road	1.5	20	1220	1.22	0.3
E100H06	rd Electronic	Electronics	hree-Wheele	TVS	1	3	3	CNG	30	20% to 40%	0.85	0.2	0	3	6	2017	-1	2	BS III	2	3	5	Sarangpur	1.5	30	580	0.58	0.38666
A10M14	PMC Jamalpu	Perishables	e-Wheeler (L	Atul Shakti	-1	1	1	Diesel	18	20% to 40%	0.8	0.3	0	3	6	2017	0	3	BS IV	-1	2	2	Narol	14	30	1240	1.24	0.34444
E100H35	rd Electronic	Electronics	e-Wheeler (L	Vikram	-1	1	1	Diesel	25	20% to 40%	0.3	0.5	1	3	4	2019	-1	2	BS III	1	3	4	Sarangpur	2	20	3330	3.33	0.39E
A100T79	PMC Jamalpu	Perishables	Two-wheeler	Honda	0	2	2	Petrol	50	80% to 90%	0.12	0.1	1	3	3	2020	-1	2	BS III	-2	1	1	-	0	5	350	0.35	0.14
E100H34	rd Electronic	Electronics	e-Wheeler (L	Vikram	-1	1	1	Diesel	25	80% to 90%	0.35	0.5	1	3	4	2019	-1	2	BS III	1	3	4	Sarangpur	3	10	1920	1.92	0.512
F100T08	npol Cloth M	Textile	e-Wheeler (L	Atul Shakti	-1	1	1	Diesel	18	60% to 80%	0.6	0.4	2	3	1	2022	1	3	BS V	0	3	3	Manek chowk	2	20	1540	1.54	0.25555
D10M26	rd Electronic	Electronics	Wheeler (Pas	Bajaj	1	3	3	CNG	24	20% to 40%	0.6	0.2	2	3	0	2023	2	3	BS VI	-1	2	2	Relief rd	14	45	420	0.42	0.19583
G100H04	w Cloth mark	Textile	e-Wheeler (L	Atul Shakti	-1	1	1	Diesel	20	40% to 60%	0.4	0.5	-1	3	8	2015	-1	2	BS III	1	3	4	w Cloth Mark	2	15	1400	1.4	0.36
G100H12	w Cloth mark	Textile	e-Wheeler (L	Vikram	-1	1	1	Diesel	25	20% or below	0.4	0.6	0	3	6	2017	-1	2	BS III	2	3	5	New Cloth M	1.5	20	950	0.95	0.16
G100H17	w Cloth mark	Textile	e-Wheeler (L	Vikram	-1	1	1	Diesel	20	40% to 60%	0.3	0.4	-1	3	8	2015	-1	2	BS III	1	3	4	New Cloth M	2	15	1800	1.8	0.31
H100T19	al Cloth Mar	Textile	e-Wheeler (L	Atul Shakti	-1	1	1	Diesel	21	0% and abov	0.7	0.65	2	3	0	2023	2	3	BS VI	0	3	3	Safal Market	1	15	1880	1.88	0.24285
G100H15	w Cloth mark	Textile	e-Wheeler (L	Atul Shakti	-1	1	1	Diesel	15	40% to 60%	0.4	0.5	0	3	6	2017	-1	2	BS III	1	3	4	w Cloth Mark	1.5	30	1700	1.7	0.41333
D100H19	rd Electronic	Electronics	e-Wheeler (L	Vikram	-1	1	1	Diesel	25	20% to 40%	0.35	0.1	-1	3	7	2016	-1	2	BS III	1	3	4	Kalupur	1.5	15	2175	2.175	0.784
H100H03	al Cloth Mar	Textile	e-Wheeler (L	Atul Shakti	-1	1	1	Diesel	20	40% to 60%	0.35	0.4	1	3	4	2019	-1	2	BS III	1	3	4	antakarna G	2	20	2800	2.8	0.7
G100H05	w Cloth mark	Textile	e-Wheeler (L	Vikram	-1	1	1	Diesel	20	60% to 80%	0.4	0.5	-1	3	8	2015	-1	2	BS III	0	3	3	Ghantakarna	2	20	500	0.5	0.1
G100H06	w Cloth mark	Textile	e-Wheeler (L	Atul Shakti	-1	1	1	Diesel	15	80% to 90%	0.35	0.4	-1	3	8	2015	-1	2	BS III	1	3	4	New Cloth M	1.5	15	600	0.6	0.13333
E100T10	rd Electronic	Electronics	e-Wheeler (L	Vikram	-1	1	1	Diesel	25	20% to 40%	0.8	0.3	2	3	0	2023	2	3	BS VI	1	3	4	Sarangpur	1.5	12	3330	3.33	0.452
G100H07	w Cloth mark	Textile	e-Wheeler (L	Vikram	-1	1	1	Diesel	20	80% to 90%	0.4	0.6	0	3	6	2017	-1	2	BS III	0	3	3	Ghantakarna	2	2	800	0.8	0.1
G100H08	w Cloth mark	Textile	e-Wheeler (L	Vikram	-1	1	1	Diesel	25	0% and abov	0.4	0.5	-1	3	7	2016	-1	2	BS III	0	3	3	New Cloth M	1.5	20	800	0.8	0.08
G100H26	w Cloth mark	Textile	e-Wheeler (L	Vikram	-1	1	1	Diesel	20	80% to 90%	0.35	0.5	-1	3	8	2015	-1	2	BS III	1	3	4	New Cloth M	2	20	900	0.9	0.15
A100T98	PMC Jamalpu	Perishables	LCV	TATA	-1	1	1	Diesel	8	80% to 90%	5	4	2	3	2	2021	0	3	BS IV	-2	1	1	APMC	0.5	20	27200	27.2	1.7
A100T09	PMC Jamalpu	Perishables	e-Wheeler (L	Atul Shakti	-1	1	1	Diesel	30	40% to 60%	0.8	0.45	2	3	2	2021	0	3	BS IV	-2	1	1	-	0	10	3060	3.06	0.45333
A100T66	PMC Jamalpu	Perishables	Wheeler (Pas	Bajaj	-1	1	1	Diesel	30	40% to 60%	0.7	0.35	2	3	2	2021	0	3	BS IV	-1	2	2	-	0	15	1120	1.12	0.21333
H100H24	al Cloth Mar	Textile	e-Wheeler (L	Vikram	-1	1	1	Diesel	20	80% to 90%	0.35	0.5	0	3	5	2018	-1	2	BS III	1	3	4	New Cloth M	1.5	20	3900	3.9	0.45
D100H22	rd Electronic	Electronics	e-Wheeler (L	Vikram	-1	1	1	Diesel	25	60% to 80%	0.4	0.2	1	3	4	2019	-1	2	BS III	1	3	4	Relief Road	2	20	1705	1.705	0.704
H100H28	al Cloth Mar	Textile	e-Wheeler (L	Vikram	-1	1	1	Diesel	22	40% to 60%	0.3	0.5	-1	3	7	2016	-1	2	BS III	2	3	5	w Cloth Mark	2	15	1400	1.4	0.41383
H100H29	al Cloth Mar	Textile	e-Wheeler (L	Vikram	-1	1	1	Diesel	25	20% to 40%	0.4	0.5	0	3	5	2018	-1	2	BS III	1	3	4	New Cloth M	2	15	3770	3.77	0.66



Survey Number	Expansion fact	Survey Location	Products transported	Vehicle type	Vehicle manufacturer	Vehicle fuel type	Vehicle fuel types for sub cat	Vehicle fuel types for sub cat	Vehicle fuel types for sub cat	Vehicle fuel types for sub cat	Vehicle mileage (Km/L)	Current vehicle occupancy	Total vehicle capacity (Tonnes)	Current weight of commodity (Tonne)	Vehicle Age	Age factor for Sub cat	Age factor for Sub cat	Age factor for Sub cat	Age factor for Sub cat	Vehicle registration year	Engine type	Engine Type for Sub Cat	Engine Type for Sub Cat	Engine Type for Sub Cat
C100T16	85.12	Kalupur St	Perishable	Three-Wheeler (LCV)	Vikram	Diesel	24.651	0	0	8512	25	40% to 60%	0.8	0.35	6	15.203	73.91304	0	0	2017	BS IV	13.935	50	4256
A100T75	11.77	APMC Jam	Perishable	Three-Wheeler (LCV)	Vikram	Diesel	24.651	0	0	1177	24	60% to 80%	0.6	0.4	2	8.491	91.30435	0	0	2021	BS IV	13.935	50	588.5
A100T43	11.77	APMC Jam	Perishable	Three-Wheeler (LCV)	Atul Shakti	CNG	5.135	100	1177	1177	25	40% to 60%	0.8	0.4	8	18.559	65.21739	76760.87	117700	2015	BS III	18.335	25	294.25
A100T27	11.77	APMC Jam	Perishable	Three-Wheeler (Passenger)	Bajaj	CNG	5.135	100	1177	1177	23	40% to 60%	0.7	0.3	1	6.813	95.65217	112582.6	117700	2022	BS V	9.535	75	882.75
A100T102	1	New Cloth	Perishable	MCV	TATA	Diesel	24.651	0	0	100	5	60% to 80%	10.5	7	9	20.237	60.86957	0	0	2014	BS III	18.335	25	25
A100T53	11.77	APMC Jam	Perishable	Three-Wheeler (LCV)	Atul Shakti	CNG	5.135	100	1177	1177	24	40% to 60%	0.8	0.4	0	5.135	100	117700	117700	2023	BS VI	5.135	100	1177
A100T56	11.77	APMC Jam	Perishable	Three-Wheeler (Passenger)	Bajaj	CNG	5.135	100	1177	1177	24	40% to 60%	0.7	0.35	11	23.593	52.17391	61408.7	117700	2012	BS III	18.335	25	294.25
A100T62	11.77	APMC Jam	Perishable	Three-Wheeler (LCV)	Atul Shakti	Diesel	24.651	0	0	1177	35	40% to 60%	0.7	0.4	0	5.135	100	0	0	2023	BS VI	5.135	100	1177
A100T77	11.77	APMC Jam	Perishable	Three-Wheeler (Passenger)	Bajaj	CNG	5.135	100	1177	1177	25	40% to 60%	0.7	0.35	12	25.271	47.82609	56291.3	117700	2011	BS III	18.335	25	294.25
A100T83	11.77	APMC Jam	Perishable	Three-Wheeler (LCV)	Atul Shakti	CNG	5.135	100	1177	1177	20	40% to 60%	0.8	0.45	0	5.135	100	117700	117700	2023	BS VI	5.135	100	1177
C100T01	85.12	Kalupur St	Perishable	Three-Wheeler (Passenger)	Bajaj	CNG	5.135	100	8512	8512	25	40% to 60%	0.7	0.3	11	23.593	52.17391	444104.3	851200	2012	BS III	18.335	25	2128
C100T10	85.12	Kalupur St	Perishable	Three-Wheeler (LCV)	Atul Shakti	CNG	5.135	100	8512	8512	42	40% to 60%	0.8	0.3	12	25.271	47.82609	407095.7	851200	2011	BS III	18.335	25	2128
A100T105	1	New Cloth	Perishable	MCV	Eicher	Diesel	24.651	0	0	100	6	60% to 80%	10.5	7.5	0	5.135	100	0	0	2023	BS VI	5.135	100	100
A100T66	11.77	APMC Jam	Perishable	Three-Wheeler (Passenger)	Bajaj	Diesel	24.651	0	0	1177	30	40% to 60%	0.7	0.35	11	23.593	52.17391	0	0	2012	BS III	18.335	25	294.25
A100T19	28.76	APMC Jam	Perishable	LCV	Eicher	Diesel	24.651	0	0	2876	9	40% to 60%	5	2.5	0	5.135	100	0	0	2023	BS VI	5.135	100	2876
A100T45	11.77	APMC Jam	Perishable	Three-Wheeler (Passenger)	Bajaj	CNG	5.135	100	1177	1177	24	40% to 60%	0.7	0.3	0	5.135	100	117700	117700	2023	BS VI	5.135	100	1177
A100T58	11.77	APMC Jam	Perishable	Three-Wheeler (Passenger)	Bajaj	CNG	5.135	100	1177	1177	26	40% to 60%	0.7	0.3	13	26.949	43.47826	51173.91	117700	2010	BS III	18.335	25	294.25
C100T06	85.12	Kalupur St	Perishable	Three-Wheeler (LCV)	Atul Shakti	CNG	5.135	100	8512	8512	40	40% to 60%	0.8	0.4	0	5.135	100	851200	851200	2023	BS VI	5.135	100	8512
A100T69	11.77	APMC Jam	Perishable	Three-Wheeler (LCV)	Atul Shakti	Diesel	24.651	0	0	1177	30	40% to 60%	0.8	0.45	11	23.593	52.17391	0	0	2012	BS III	18.335	25	294.25

2. CVC DATA

Time Slots	Hand cart (goods)	2-wheeler (goods)	3-wheeler (goods)	LCV (2-8 ton)	MCV (8-16 ton)	HCV (above 16 ton)	Cycle (goods)	Others
03:00AM to 04:00AM	2	0	25	21	9	0	11	0
04:00AM to 05:00AM	4	0	38	16	11	0	29	0
05:00AM to 06:00AM	1	0	34	24	6	0	33	0
06:00AM to 07:00AM	2	1	54	24	17	0	34	0
07:00AM to 08:00AM	12	2	46	23	11	0	29	0
08:00AM to 09:00AM	8	1	71	21	6	0	29	0
09:00AM to 10:00AM	6	0	29	12	0	0	24	0
10:00AM to 11:00AM	12	1	69	17	5	0	20	0
11:00AM to 12:00PM	4	3	109	35	9	0	24	0
12:00PM to 01:00PM	2	2	82	22	11	0	22	0
01:00PM to 02:00PM	0	1	103	29	9	0	21	0
02:00PM to 03:00PM	0	2	103	31	6	0	23	0
03:00PM to 04:00PM	20	2	122	22	8	0	14	0
04:00PM to 05:00PM	17	0	119	19	7	0	9	0
05:00PM to 06:00PM	9	0	121	13	7	0	18	0
06:00PM to 07:00PM	1	1	118	17	8	0	16	0
07:00PM to 08:00PM	3	0	155	28	14	0	18	0
08:00PM to 09:00PM	2	0	150	32	9	0	20	0

Kalupur | APMC Jamalpur | Delhi Darwaja | Tilok Park | Astodiya | Sarangpur

○ Appendix C: Stakeholder and expert interview list

List of stakeholders:

1. Mr. Ketan Modi (Environmental Engineer)
2. Mr. Sunny Kodukula (Director – Research and Capacity Building, UEMI)
3. Dr. Leeza Malik (Assistant Professor, Indian Institute of Technology – Dhanbad)
4. Dr. Naveen Thomas (Assistant Professor, Urban Transportation Planning and Modelling, Department of Economics and Public Policy, OP Jindal University)
5. Dr. Sarath Guttikunda (Founder/Director, Urban Emissions)
6. Prof Shivanand Swamy (Director Emeritus, CoE-UT, CRDF)
7. Mr Amit Bhatt (Managing Director, ICCT, India)
8. Dr. Debjit Roy (Institute Chair Professor, Indian Institute of Management Ahmedabad)
9. Dr. Neha Upadhyay (Environmental Engineer, Ahmedabad Municipal Corporation)
10. Ms. Sarika Chakravarty (Team Lead, National Institute of Urban Affairs)

The Urban Lab Foundation
The Urban Lab, 108, Synergy Tower,
Corporate Road, Prahladnagar,
Ahmedabad, Gujarat, India, 380015
Tel: (079) 48900912
Email: Info@theurbanlab.org
Web: tulfoundation.org

HIGH VOLUME TRANSPORT
APPLIED RESEARCH

UK International Development
Partnership | Progress | Prosperity