ASSESSING THE COMBUSTION GENERATED EMISSIONS FROM THE VEHICULAR EXHAUST IN ISLAMABAD, PAKISTAN

By

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ABSTRACT

A study was conducted to evaluate the level of air pollution caused by vehicular emissions in selected areas of Islamabad, the capital city. A total of 300 vehicles, categorized by fuel type (Petrol, CNG, and Diesel), were tested in collaboration with Steinol Solutions Pvt Ltd (SSPL) and the Pakistan Environmental Protection Agency (Pak-EPA) for four primary toxic pollutants: CO, NOx, CO_2, and hydrocarbons. The test took place at five distinct locations within Islamabad. The concentrations of these pollutants were analyzed for different vehicles, and the measured values were compared with the National Environmental Quality Standards (NEQS). Maximum hydrocarbons were emitted by CNG-powered vehicles as compared to gasoline powered vehicles. At the same time, CO from petrol vehicles was greater than all other pollutants and sources. Older models from Honda, Suzuki, Toyota have been linked to high CO, CO_2, and HC emissions. Hyundai, Mazda, Toyota, and Nissan have also shown high NOx emissions and smoke opacity issues, often due to lack of proper maintenance and brakes. Statistical analysis of the data revealed that the current state of vehicular emissions in Islamabad is extremely poor, highlighting the urgent need for the development of strategies applicable across Pakistan. Factors contributing to this situation include fuel quality, traffic congestion, and insufficient vehicle maintenance. Collaborative efforts among government authorities, environmental agencies, and the community will be crucial in fostering a cleaner and healthier urban environment for all residents.

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ABBREVIATIONS

VOCs	Volatile Organic Compounds
NDIR	Non -Dispersive Infrared
NH & MP	National Highway and Motorway Police
CNG	Compressed Natural Gas
LPG	Liquid Petroleum Gas
NMVOC	Non-Methylated Volatile Organic Compounds
JICA	Japan International Corporation Agency
ICT	Islamabad Capital Territory
$\mu g/m^3$	Microgram Per Cubic Meter
PM	Particulate Matter
NEQS	National Environmental Quality Standards
AQI	Air Quality Index
PAMA	Pakistan Automotive Manufactures Association
MVE	Motor Vehicle Examiners
WHO	World Health Organization
EPA	Environmental Protection Agency
PAHs	Polycyclic Aromatic Hydrocarbons
SO_2	Sulfur Dioxide
NO	Nitric Oxide
Pb	Lead
CO	Carbon Monoxide
O_3	Ozone
ARAI	Automotive Research Association of India
ETO	Excise and Taxation Office
M-1	Motorway
DNA	Deoxyribose-Nucleic Acid
IDC	Indian Driving Cycle
EU	European Union

CONTENTS

Page

CHAPTER 1
INTRODUCTION

CHAPTER 2
MATERIAL AND METHODS

CHAPTER 3
RESULTS AND DISCUSSION

FIGURES

TABLES

CHAPTER 1
INTRODUCTION

1.1 Research background

With the increase in global population and the corresponding human demands, vehicular traffic has increased rapidly, threatening the environment of urban areas. Today, the leading cause of primary air pollution is the Vehicular Emissions, which is significantly deteriorating the air quality (Pandian et al., 2009; He et al., 2002; Mayer, 1999). The number of vehicles worldwide grew to 700 million by the year 2000. This substantial increase in the vehicular population has intensified the global air quality crisis, with 40–80% of urban air pollution attributed to automobile emissions. Pollution from vehicular Volatile Organic Compounds (VOCs) poses more serious threats to developing countries compared to the developed world, such as the Europe and the United States. This is illustrated by VOC data from Pakistan, India, Egypt and Thailand (Kamal et al., 2012; Arayasiri et al, 2010; Chan and Yao, 2008).

The estimation of vehicular emissions, particularly from light-duty vehicles (LDVs), is a critical concern for urban air quality and climate change mitigation. In rapidly growing cities like Islamabad, the increasing number of vehicles has contributed significantly to deteriorating air quality, with LDVs being a major source of pollutants such as carbon dioxide (CO_2), nitrogen oxides (NOx), particulate matter (PM), and volatile organic compounds (VOCs) (Shahbaz et al., 2021).

Advancements in technology have yet to counteract the rise in vehicular pollution. As a result, it is projected that air quality in cities may continue to decline in the future. This trend clearly illustrates the direct relationship between air pollution and vehicular emissions, such as carbon monoxide (CO), ozone (O3), and particulate matter. (Davis, 1998).

Automobiles release particulate matter, including sub-micron particles (PM10), which have been directly associated with high mortality rates (Anon, 1995), highlighting their significant role in air contamination. Vehicular exhaust and industrial facilities also emit NO2, which, through photochemical reactions, produces ozone (O3). Ozone exacerbates allergic asthma by enhancing allergic responses. Similarly, sulfur dioxide (SO2), nitric oxide (NO), acidic aerosols, and particulates affect the pulmonary tract and can cause inflammation of bronchia (Karen and Michak, 1991). Furthermore, numerous research highlights the crucial part that air pollution plays in the onset and aggravation of allergy problems, frequently characterizing it as a disease of civilized society (Bonai et al., 1994)

In order to evaluate vehicular emission pollution and related environmental and health impacts, a survey has been carried out at an Indian megacity which quantified the air pollution and its vulnerability index at traffic intersections. Additionally, according to UN reports, over 600 million people live in cities worldwide and are exposed to dangerously high amounts of air pollution caused by vehicle traffic (Cacciola et al., 2002).

The risk of air pollution and its effects is currently drawing much attention from environmental health advocates, environmental regulatory agencies, industrial facilities and the public. It is accepted worldwide that air quality, outdoor as well as indoors, is associated with defects and deaths from pulmonary and cardiovascular disorders (Ibrahim et al., 2012).

1.2 Analysis of Emissions from Vehicles

Engines in vehicles operate on various kinds of fuels that are burned by the process of combustion. Air pollution is caused by exhaust gases released into the atmosphere during the combustion process and fuel evaporation.

The exhaust gases and emissions due to evaporative losses are the key pollutants from automobiles as illustrated in the figure.

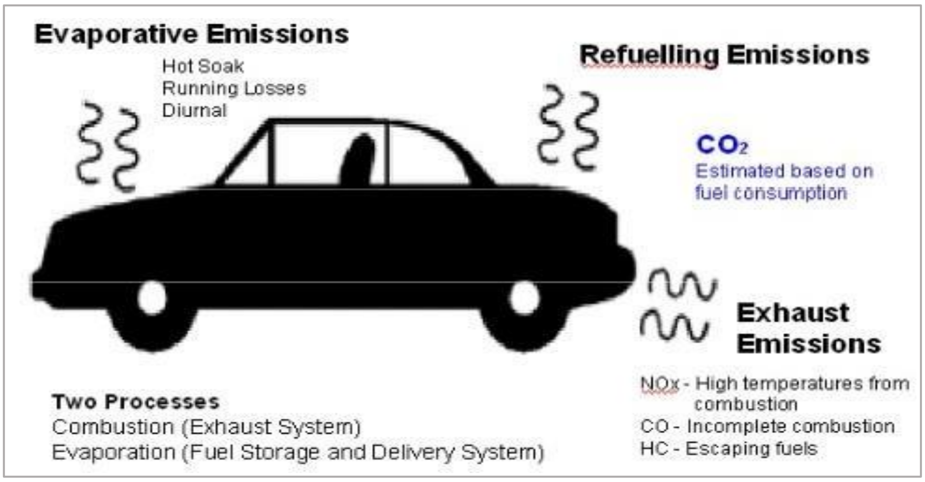


Figure 1.1 Vehicular Emissions (Nikolaos., 2019)

The fuels that power a vehicle is generally composed of hydrocarbons i.e. compounds consisting of carbon and hydrogen elements. In an ideal condition, when fuel is burnt oxygen combines with hydrogen and converts it into water, whereas carbon will be transformed into carbon dioxide (CO_2). There would be no effect on the aerial nitrogen, and the atmospheric balance will remain unchanged. Nevertheless, fuel combustion is never ideal, and in real scenario vehicular engines emit several types of pollutants. Nitrogen (NO, NO2), carbon (CO, CO_2), sulfur (SO2), and oxygen oxides are typically among them.

Hydrocarbon fuels are comprised of 10 to 20 major species and some 100 to 200 species. Most of them are found in exhaust. However, some of the exhaust HC are not found in parent fuel, but they are derived from the fuel whose structure was altered in the cylinder by chemical reaction that did not go to completion. There are about 50% of the total hydrocarbon emitted. These partial reaction products include Aceta-aldehyde, formaldehyde, 1-3 butadiene and Benzene.

The most common air pollutants that cause concern for regulatory agencies and environmentalists include sulfur dioxide (SO2), lead oxide (from leaded fuels), ozone (O3), carbon monoxide (CO), nitrogen dioxide (NO2), particulate matter, polycyclic aromatic hydrocarbons (PAHs) and lastly the Volatile Organic Compounds (VOCs) (Rekhadevi et al., 2010). However, ozone (O_3) is regarded as a secondary pollutant in addition to lead and sulfur dioxide, as they receive comparatively little concerns (Han and Naeher, 2006).

1.2.1 Two Stroke and Four Stroke Cycle

Two-stroke engines complete a cycle in two strokes of the piston (one crankshaft revolution). During the upward stroke, the piston compresses a mixture of air and fuel in the combustion chamber while simultaneously drawing in a new charge from the crankcase (Heywood, 1988). When the piston reaches the top, the spark plug ignites the mixture, causing an explosion that forces the piston downward. As the piston descends, it uncovers the exhaust port, allowing burnt gases to escape while pushing in a fresh air-fuel mixture. This design enables two-stroke engines to produce power with every revolution of the crankshaft, resulting in higher power output but also higher emissions due to incomplete combustion (García & Verma, 2020).

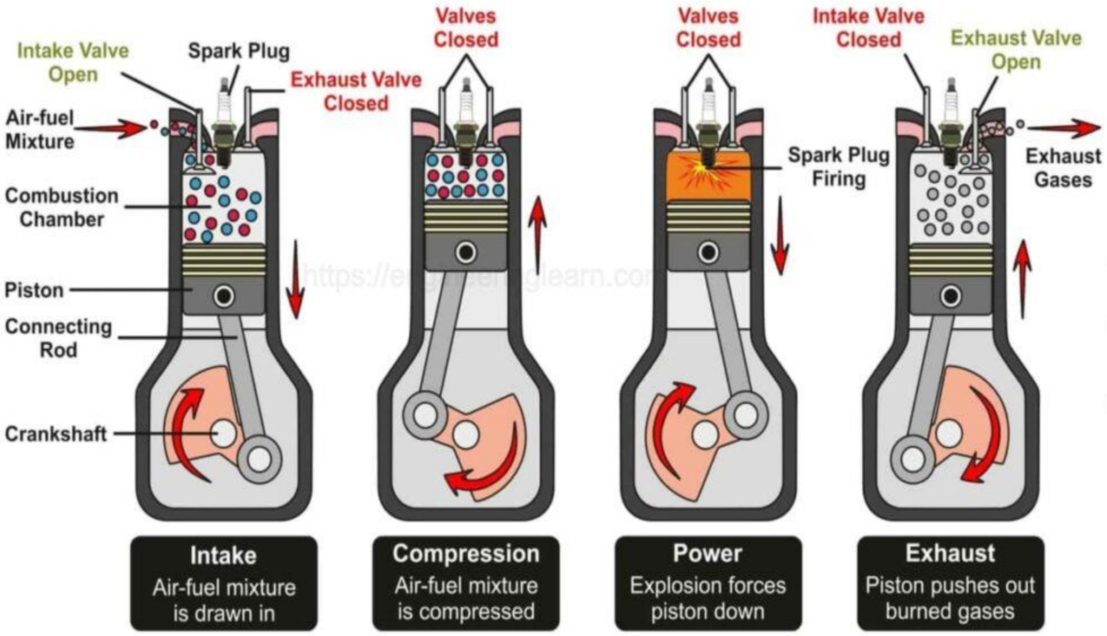


Figure 1.2 Emissions Comparison: Two-Stroke vs. Four-Stroke Engines

Four-stroke engines, on the other hand, require four strokes of the piston (two revolutions of the crankshaft) to complete a power cycle. The cycle begins with the intake stroke, where the piston moves down, creating a vacuum that draws in an air-fuel mixture through the intake valve (Heywood, 1988). The piston then moves up during the compression stroke, compressing the mixture. At the top, the spark plug ignites the mixture, leading to a power stroke that forces the piston down. Finally, during the exhaust stroke, the piston moves back up, opening the exhaust valve to expel the spent gases. Four-stroke engines produce power every two revolutions, making them more efficient and typically resulting in lower emissions compared to two-stroke engines due to better combustion control (Miller, 2017).

1.2.2 Exhaust Pollutants

i. Hydrocarbon (HC)

When fuel in an engine either doesn't burn at all or burns partially, hydrocarbons are released into the environment and in the presence of the sunlight, these hydrocarbons gets combined with nitrogen dioxide to produce tropospheric ozone.

Ozone is a significant constituent of smog. Ozone is also responsible for public health implications such as eye irritation, lungs disorders and diseases pulmonary system. Several other hydrocarbons are also hazardous in themselves and may cause cancer. Therefore, hydrocarbon emission is subject of serious concern as an urban air pollutant (Milt et al., 2003).

ii. Oxides of Nitrogen (NO_X)

Nitrogen and oxygen in the atmosphere react under elevated temperature max at (2500-3000 ° kelvin) and pressure in the vehicular engine and forms different oxides of nitrogen, commonly referred as NOx. These oxides of nitrogen, like hydrocarbons, participates in the production of ozone (O_3). NOx react with water vapor to form Nitric Acid, and they are also responsible for the acid rain formation (Nazarenko et al., 2017).

iii. Carbon monoxide (CO)

The combustion of fuel in an automobile engine releases carbon dioxide and carbon monoxide when the carbon is oxidized in the air. The product of incomplete oxidation and partial burning is carbon monoxide (CO).

As a pollutant, it is a highly toxic gas as it replaces the oxygen in the blood and affects the optimum blood flow conditions. CO has an affinity for hemoglobin about 200 times that of oxygen. The situation is especially alarming for individuals with cardiovascular disorders (Tsai et al., 2017). Carbon Dioxide (CO_2)

The product of an optimal combustion process is carbon dioxide, however; the EPA (Environmental Protection Agency) of United States currently views it as a significant pollutant. Public health is not directly impacted by carbon dioxide (CO_2). It is one of greenhouse gases and produces greenhouse effect leading to global warming (Verner and Sejkorova, 2018).

1.2.3 Evaporative Emissions

Air pollution is also caused by the contaminants that escape into the atmosphere due to the evaporation of fuels. With the application of advanced and efficient vehicular fuel metering and evaporative control systems and effective gasoline reformulation, losses of pollutants to air due to evaporation is controlled to the limit. Evaporative losses are maximum during the hot season and day time, when the level of ozone is also highest.

1.3 Influencing Factors of Automotive Emission

The problem of traffic emissions increases with disturbed flow and delays particularly at traffic intersections and junctions or stop signals. It results in idle flow rate, vehicles queuing and cruise driving modes. All these characteristics related to traffic and road etc. raising the emissions as identified by (Pandian et al., 2009) since there is a correlation between emissions and a vehicle's type, size, age, and engine condition as well as emission control system’s type and condition, characteristics of the engine, as well as its maintenance and weight.

The size of the engine also affects how emission control devices/equipment operate (Beydoun, 2004). The exhaust emission is also influenced by the fuel's quality. (Perry and Gee, 1995). Pandian et al., 2009 also described the different characteristics of traffic, road and vehicles as factors responsible for producing the vehicular emission

Table 1.1 Traffic, road, and vehicle characteristics in relation to the emissions at traffic intersection (Source: Pandian et al., 2009)

Characteristic Type	**Specific Characteristic**	**Emission Impact**	**Description**
Traffic	Traffic Volume	Increased Emissions	Higher traffic volume leads to congestion, increasing emissions.
Traffic	Stop-and-Go	Increased Emissions	Frequent stopping and acceleration increase emissions.
Traffic	Average Speed	Varied Emissions	Lower speeds in congested areas increase emissions per vehicle.
Road	Intersection Design	Increased Emissions	Poorly designed intersections lead to longer idling times.
Road	Traffic Signal Timing	Increased Emissions	Inefficient signal timing increases stop-and-go traffic.
Road	Road Gradient	Increased Emissions	Steeper roads lead to higher fuel consumption and emissions.

Vehicle	Vehicle Speed	Increased Emissions	Higher speeds increase emissions, especially CO and NOx.
Vehicle	Vehicle Type	Varied Emissions	Heavy-duty vehicles emit more pollutants than light-duty vehicles.
Vehicle	Fuel Type	Varied Emissions	Fuel type affects emission levels; alternative fuels generally emit less.

1.4 Quality of Air in Pakistan

Pakistan is striving to fight climate change. It’s a challenge to combat the issue due to less institutional capacity and lack of direction. Pakistan’s major urban areas are polluted to the same extent as world’s highly polluted areas as per WHO reports. It is estimated that 60 $\mu g/m^3$ (microgram per cubic meter) of $PM_{2.5}$ particulates are present in the air of Pakistan. The value is four times higher than the permissible limits recommended by Pakistan Environmental Protection Agency's National Environmental Quality Standards (NEQS) for Ambient Air (PK-EPA).

The declining quality of the air could be extremely dangerous for human health, increasing the prevalence of respiratory and cardiovascular conditions in the general population. It is reported that 59,241 mortalities are attributed to the air pollution every year in Pakistan (WHO, 2016). Major cities of Pakistan are highly polluted as per WHO 2016 Global Urban Ambient Air Pollution database

Key findings for PM_{10} concentrations of the report are tabularized in table 1.2.

Table 1.2. Air Quality of mega global cities (Global Urban Ambient Air Pollution Database 2024)

S.no	Cities	PM_{10} conc.(µg/m^3)
1	Peshawar	111
2	Rawalpindi	107
3	Karachi	88
4	Lahore	68
5	Islamabad	66
6	Dehli	122
7	Beijing	851
8	Paris	18
9	London	15
10	Pak-EPA limit	15
11	WHO limit	10

The concentration of PM_{10} in the cities of Pakistan is 6 to 10 times higher than the recommended values. Whereas, vehicular emissions are the major cause of pollution among many other pollution sources.

1.5 Current Status of Vehicular Emissions in Pakistan

Pakistan's automotive sector has grown in recent years along with the country's notable rise in per capita income. Over time, cities have seen increases in both the density of their roads and the vehicles registered annually. The expected number of cars has increased over the past 20 years, from roughly 3 million to approximately 15 million.

It has aggravated the air pollution problems in the area. Karachi, Peshawar and Islamabad also have poor Air Quality Index (AQI) (Business Recorder, October 2018). According to Pakistan Automotive Manufactures Association (PAMA), as published in Dawn News: ―There are no standards evolved for the automobile produced in Pakistan nor are there any labs to check the standards of safety etc.‖ (Shirwani et al.,2019)

1.6 Legal Framework and Regulations

Pakistan Environmental Protection Act 1997 has addressed vehicular air pollution under section 15, and in the National Environmental Quality Standards. Nevertheless, the institutional arrangement and required regulations have not been made to execute this act and NEQs. Nowadays, it is mandatory to get commercial automobiles examined by MVE (Motor Vehicle Examiners) regularly. The capacity and obligations of MVEs are defined by Motor and vehicular Authority (MVA,2006).

1.7 European Guidelines on Vehicle Emissions

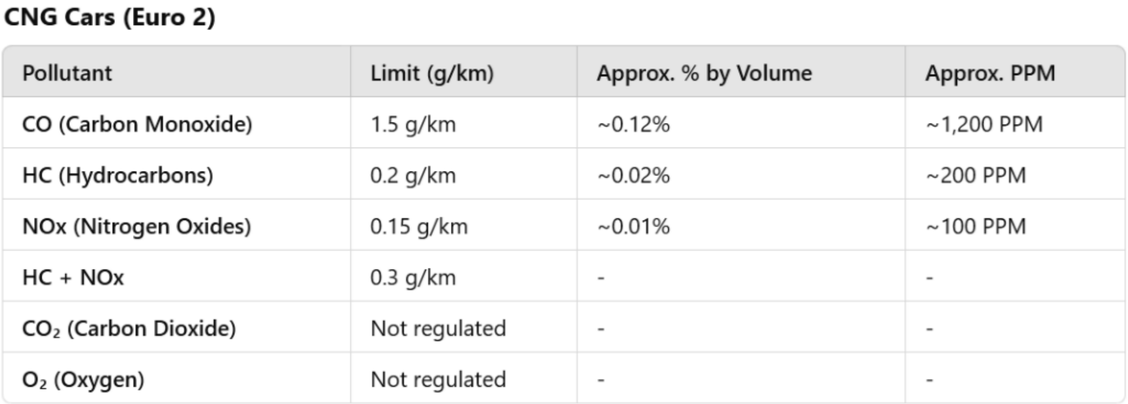
Emission standards and Regulations in Pakistan

Table 1.3. European Standards for Vehicular Emissions

Emissions Standard	**Implementation Date**	**Applicable Vehicles**	**Pollutants Regulated**
Pakistan Environmental Protection Act 1997, Section 15	1997	All motor vehicles	Carbon Monoxide (CO), Hydrocarbons (HC), Nitrogen Oxides (NOx), Particulate Matter (PM)
National Environmental Quality Standards (NEQS)	1997	All motor vehicles	Same as above
Mandatory Inspection of Commercial Automobiles by Motor Vehicle Examiners (MVE)	2006	Commercial automobiles	Compliance with NEQS
Euro 1	July 1992	New passenger cars	CO: 2.72g/km, HC + NOx: 0.97g/km, PM: 0.14g/km

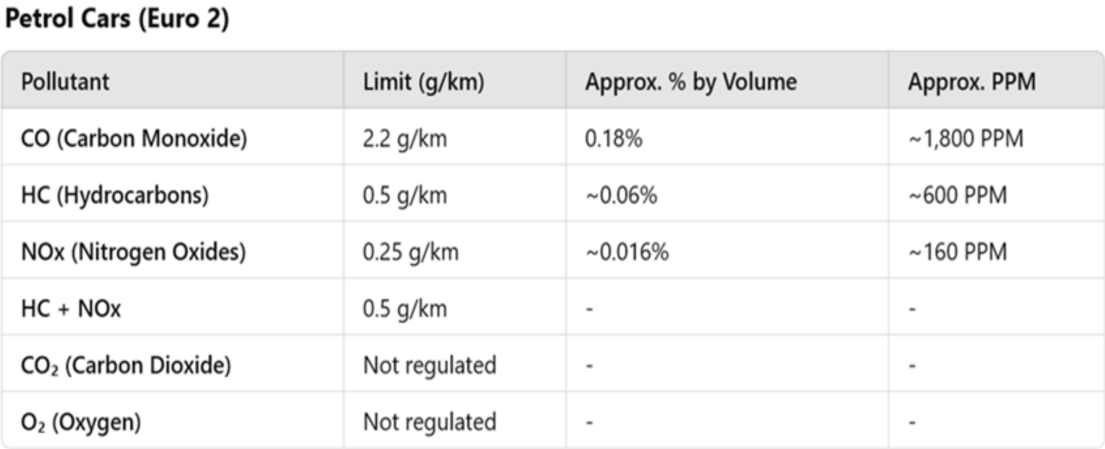
Euro 2	July 1996	New passenger cars	CO: 2.2g/km, HC + NOx: 0.5g/km, PM: 0.08g/km
Euro 3	January 2000	New passenger cars	CO: 2.3g/km, THC: 0.20g/km NOx: 0.15g/km PM: 0.05g/km
Euro 4	January 2005	New passenger cars	CO:1.0g/km, THC:0.10g/km NOx: 0.08g/km PM: 0.025g/km
Euro 5	September 2009	New passenger cars	CO:1.0g/km THC: 0.10g/km, NMHC: 0.068g/km, NOx: 0.06g/km PM: 0.005g/km
Euro 6	September 2014	New passenger cars	CO:1.0g/km THC: 0.10g/km, NMHC:0.68g/km, NOx: 0.06g/km PM:0.005g/km (direct injection only)

Euro 2 & 3 Standards in Pakistan



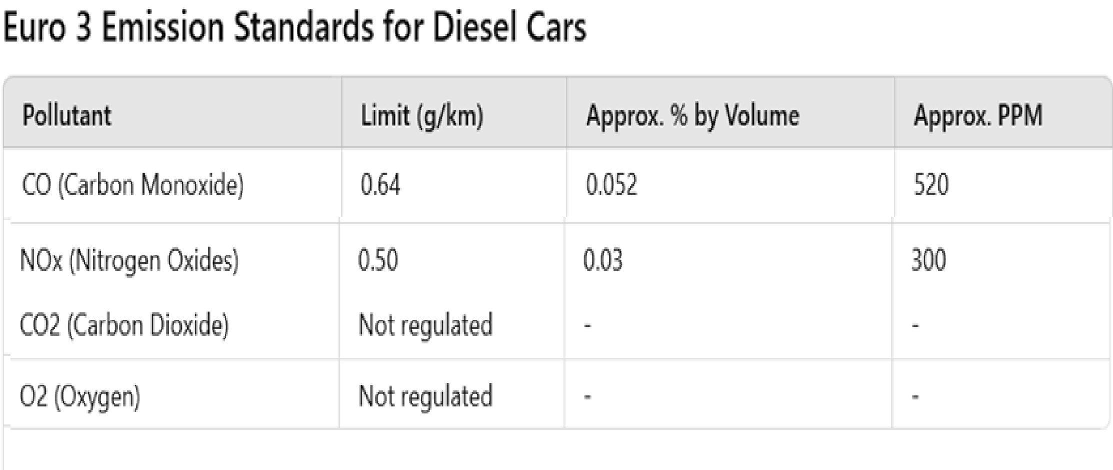
CNG Cars (Euro 2)

Pollutant	Limit (g/km)	Approx. % by Volume	Approx. PPM
CO (Carbon Monoxide)	1.5 g/km	~0.12%	~1,200 PPM
HC (Hydrocarbons)	0.2 g/km	~0.02%	~200 PPM
NOx (Nitrogen Oxides)	0.15 g/km	~0.01%	~100 PPM
HC + NOx	0.3 g/km	-	-
CO_2 (Carbon Dioxide)	Not regulated	-	-
O_2 (Oxygen)	Not regulated	-	-



Petrol Cars (Euro 2)

Pollutant	Limit (g/km)	Approx. % by Volume	Approx. PPM
CO (Carbon Monoxide)	2.2 g/km	0.18%	~1,800 PPM
HC (Hydrocarbons)	0.5 g/km	~0.06%	~600 PPM
NOx (Nitrogen Oxides)	0.25 g/km	~0.016%	~160 PPM
HC + NOx	0.5 g/km	-	-
CO_2 (Carbon Dioxide)	Not regulated	-	-
O_2 (Oxygen)	Not regulated	-	-



Euro 3 Emission Standards for Diesel Cars

Pollutant	Limit (g/km)	Approx. % by Volume	Approx. PPM
CO (Carbon Monoxide)	0.64	0.052	520
NOx (Nitrogen Oxides)	0.50	0.03	300
CO2 (Carbon Dioxide)	Not regulated	-	-
O2 (Oxygen)	Not regulated	-	-

1.8 Monitoring System for Vehicular Emissions

To reduce air pollution, the United States Environmental Protection Agency (US-EPA), the European Union (EU), and the Automotive Research Association of India (ARAI) have established regulations for vehicle exhaust emissions (ARAI, 2016). These standards were devised after experimentation and various tests carried on in the chassis dynamometer studies. Several regulatory bodies use emission models (i.e., COPERT, PHEM, EMFAC, and MOVES) to estimate emissions as control strategies (Sturm et al., 2005). Mostly dynamometer is used to emissions estimation at the controlled laboratory scale based on different driving cycles. To forecast the urban air quality, the results are additionally added to the dispersion models. In this way ,it is used to make the policies(Hagemann et al., 2004).

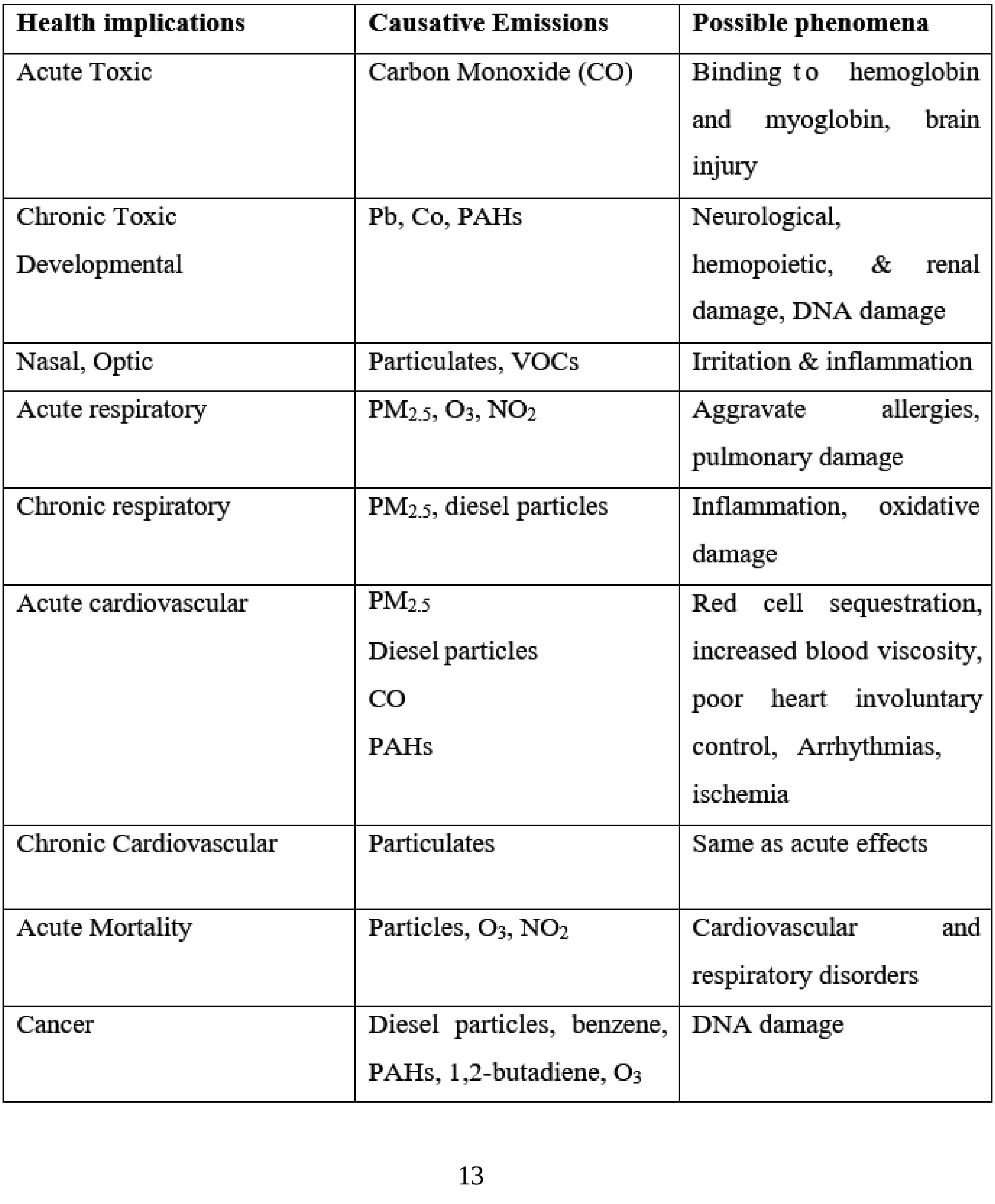
Remote Sensing, Car Chaser Technique, Road Tunnel studies and on-board monitoring in probe vehicles (Corsmeier et al., 2005) are also used to estimate emissions in the real-world scenario. Road tunnel studies were reported with some limitations of under prediction (Pierson et al., 1996; Hickman and Geller, 2005). Across Road Studies were also carried out using Remote Sensing that involves optical measurement devices with UV and IR sensors for emissions monitoring (Jimenez 1999). It has applications such as reliability testing of the control systems and vehicle screening by law enforcement for high value of emission. (Williams et al., 2003).

In the running conditions of data collection, now there are different sophisticate instrumentations i.e., portable emission monitoring systems (PEMS)(Frey and Unal, 2002). According to Zhao et al. (2008), the PEMS outcomes are assessed based on many traffic variables, including road shape, signalization, and the kind of traffic flow. The EU Regulatory Design of command and control (EU CAS) also applies on-board emission measurements to the real-time scenarios (Skeete, 2017).

1.9 Health Consequences of Vehicular Emissions

Vehicle exhaust emissions, being potent air pollutants are causing adverse health effects (directly and indirectly) as their by-product gases and particles have effects on, cardiovascular disease, respiratory disease, mortality, fetal development etc. (Table 1.4). By controlling the fuel composition and the design and operation of vehicle engines, it can be reduced.

Table 1.4: Health Implications of Vehicular Emissions
(Vehicular Exhausts, M Burr and C Gregory, Cardiff University, Cardiff, UK and 2011 Elsevier B.V)



Health implications	**Causative Emissions**	**Possible phenomena**
Acute Toxic	Carbon Monoxide (CO)	Binding to hemoglobin and myoglobin, brain injury
Chronic Toxic Developmental	Pb, Co, PAHs	Neurological, hemopoietic, & renal damage, DNA damage
Nasal, Optic	Particulates, VOCs	Irritation & inflammation
Acute respiratory	$PM_{2.5}$, O_3, NO_2	Aggravate allergies, pulmonary damage
Chronic respiratory	$PM_{2.5}$, diesel particles	Inflammation, oxidative damage
Acute cardiovascular	$PM_{2.5}$ Diesel particles CO PAHs	Red cell sequestration, increased blood viscosity, poor heart involuntary control, Arrhythmias, ischemia
Chronic Cardiovascular	Particulates	Same as acute effects
Acute Mortality	Particles, O_3, NO_2	Cardiovascular and respiratory disorders
Cancer	Diesel particles, benzene, PAHs, 1,2-butadiene, O_3	DNA damage

1.10 Overview of the Current Study

Current study was conducted in Islamabad(capital), Pakistan. The territory is bounded by Punjab and Khyber Pakhtunkhwa provinces which covers 906 km^2 (349.8 mi^2) area. This study is intended to monitor the pollution caused by Islamabad's high traffic volume in a few chosen high traffic zones.

A network of motorways, such as the M-2 Motorway (228 mi) that connects Islamabad to Lahore and the M-1 Motorway (96 mi) that connects Islamabad to Peshawar, connects all major cities and towns to Islamabad.

Urbanization, population growth, and industrial activity have all contributed to a sharp rise in the number of vehicles in Islamabad, the capital of the country. As a result, we are currently threatened by a range of air contaminants that originate from both automobile traffic and other sources. (Shah et al., 2006).

The Excise and Taxation Office (ETO) Islamabad have registered almost 0.7 million vehicles till to date. Different schemes offered by banks etc. have caused a significant increase in the number of vehicles in the city. Around 6,000 vehicles per month and 200 cases per day around 6,000 automobiles a month and 200 instances daily (50–70 motorcycles, 90–100 personal vehicles, four–five commercial vehicles, and ten–fifteen government vehicles, respectively) (Nespak, 2016). So, it is important to assess/monitor the emissions for getting the baseline for better policy and management.

Different studies evidenced overburdened local atmosphere comprising of PMs and toxic trace metals (Shah et al., 2003). The environment of the city is almost comparable to that of any global grossly polluted city (JICA, 2000).

Shah and Shaheen, 2003 reported higher atmospheric metals concentration (iron, zinc, manganese, lead, Cadmium and potassium) in contrast to urban areas in Europe as a result of human causes (i.e., vehicle emissions, industry, burning processes, and mineral dust). The overall situation is thus posing a health hazard to the population living in that area.

1.11 Aims and Objectives

Keeping background of vehicular pollution and associated problems, this study was conducted with the following specific aims and objectives.

i. To assess the vehicular emissions in Islamabad, categorized by fuel types (Petrol, CNG, diesel) to understand the air pollution levels
ii. Determine if emissions exceed NEQS limits for CO, NOx, CO_2, and unburnt hydrocarbons, identifying non-compliant vehicles and fuels.
iii. Assessing the Survey responses and emission testing data for understanding variations in emissions levels among different vehicles.

1.12 Literature Review

Similar studies on national and international scale were reported here after reviewing different literature with the same background**.**

Ayub, Mahmood, and Sarwar (2024) examine the role of transportation in contributing to smog formation in Lahore, Pakistan was examined. Their analysis highlights those vehicular emissions, particularly from diesel and petrol-powered vehicles, are a major source of air pollutants, including nitrogen oxides (NOx) and particulate matter (PM). These pollutants, when combined with atmospheric conditions such as temperature inversions, significantly contribute to the recurrent smog events in the region, posing serious health risks to the local population. The study emphasizes the need for stricter emission control measures and alternative transportation solutions to mitigate smog formation in Lahore.

Nazir and Shah (2023) conducted a comprehensive evaluation of air quality in Islamabad, focusing on the health risks associated with trace elements found in PM2.5 particulates, which are significantly influenced by vehicular emissions. Their study revealed that toxic trace elements such as lead, nickel, and arsenic, often linked to motor vehicle exhaust, were detected in concentrations that exceed recommended safety limits. The presence of these elements in respirable particulates raises serious concerns about public health, particularly regarding the development of respiratory and cardiovascular diseases. It emphasize that the deteriorating air quality, exacerbated by the increasing number of vehicles on the road, necessitates the implementation of stringent emission standards and the adoption of cleaner transportation alternatives. They advocate for ongoing monitoring of air quality and targeted interventions to address pollution from vehicles, thereby protecting the health of vulnerable populations in urban areas like Islamabad. Bajwa and Sheikh (2023) conducted a review of the impact of road transport on air pollution in urban Pakistan. They found that the growing number of vehicles, outdated technology, and low-quality fuels contribute significantly to emissions of pollutants like particulate matter (PM) and nitrogen oxides (NOx).

In Pakistan, however, the implementation of such standards faces challenges due to regulatory hurdles, lack of public awareness, and the predominance of older vehicles that do not comply with these norms (Khan et al., 2021).

Studies have shown that the transportation sector in Pakistan, especially in metropolitan regions, is responsible for approximately 20% of total CO_2 emissions, with LDVs contributing a substantial portion (Ali et al., 2020). The introduction and enforcement of improved emission standards, such as Euro 4 and Euro 5, offer substantial climate co-benefits by not only reducing greenhouse gas (GHG) emissions but also curbing the levels of harmful pollutants, leading to improved public health outcomes (Azam et al., 2019).

Internationally, the adoption of stricter vehicle emission standards has been linked to a reduction in both short-lived climate pollutants (SLCPs) and long-term GHGs, which helps in meeting national climate targets under the Paris Agreement (Agarwal & Verma, 2018). For instance, the transition to Euro 5 emission standards in several countries has demonstrated a reduction of 40-60% in NOx emissions from LDVs (Baidya & Parikh, 2020. Despite these challenges, the enforcement of stricter emission standards is essential to reduce the environmental impact of vehicular emissions and realize the co-benefits for both climate and public health.

The study was conducted to examine the trend of pollutants implicated in NO2 processes in traffic locations in Barcelona, Madrid, and Granada between 2003 and 2014. They came to the conclusion that NOx emissions in Barcelona, Madrid, and Granada required to be lowered by 78%, 56%, and 16%, respectively, in order to achieve the yearly NO2 limit of 40 $\mu g/m^3$. Casquero et al., (2019).

Another study was conducted to measure and analyze the PM2.5 emissions from Taiwan's Kaohsiung City's diesel cars. They discovered that the age and mileage of the vehicle had a substantial impact on emissions. The lowest CO and NOx emission factors were found in vehicles with lower cumulative mileage, whereas the highest emission factors were found in vehicles with mileages between 20,000 and 30,000 km. Lin et al, (2019).Calculated emission factors for NO, CO, and CO_2 based on on-road observations and measured exhaust emissions from a sample of light-duty vehicles that are still in use. They found that low speed and poor fuel efficiency were associated with high CO emissions. Angelo et al., (2018)

Experimental study of on-road vehicular exhaust emissions in heterogeneous traffic conditions. Evaluations released indicate that emissions during idling and cruising are generally lower than during acceleration. Pointing out the large effect of driving behavior on emissions. Jaikumar et al., (2017). Examined the exhaust emissions of gaseous pollutants, particulate matter, and mobile source air toxics (MSATs) from vehicular sources in Delhi, India, from 1991 to 2020. They found that the majority of emissions of CO, acetaldehyde, hydrocarbons (HC), and PAHs came from private vehicles, particularly two-wheelers. During this time, the main sources of emissions of CO_2, 1,3-butadiene, benzene, formaldehyde, and total aldehyde were private automobiles. Nagpure et al., (2016)

Using the COPERT model, which assigns different vehicle emission factors in line with China's vehicle emission standards, they combined street sites to calculate nationwide emissions estimation for 1999-2011. They found that automobiles and motorcycles were the main emitters of CO and NMVOCs, while heavy-duty trucks were responsible for most NOx emissions. Lang et al., (2014). To Measure the travel duration and roadside carbon monoxide and particulate matter exposure along major Lahore roadways in November 2007. They continuously measured the amount of carbon monoxide and particulate matter at 36 different points throughout the city while commuting in an air-conditioned car. Their findings indicated that traffic congestion led to high automobile exhaust emissions and the resuspension of road dust. Colbeck et al., (2011)

To examine trends in vehicle emissions in China's megacities, multi-year inventories of vehicle emissions for Beijing, Shanghai, and Guangzhou were created between 1995 and 2005. They noticed that emissions of CO, HC, NOx, and PM10 had begun to slow and even decline due to effective emission control measures. Passenger cars and large vehicles, including heavy-duty trucks and buses, were responsible for 70% and 80% of vehicular NOx and PM10 emissions, respectively (Wang et al., 2010). Investigation of the effects of motor vehicle activity-related air pollution on a local, regional, and global scale while taking institutional, behavioral, and technological aspects into account. The study strongly recommended the implementation of traffic policies and systems to address the current air quality challenges in the country (Ilyas, 2007)

Reviewing the advancements in emission control technologies and management strategies over the past decade. They discovered that 80.2% of the PM10 emissions from vehicular tailpipes in Beijing were PM 2.5. Despite a 60% increase in the population of vehicles between 1998 and 2003, total vehicular emissions did not rise, thanks to stringent emission control measures. Hao et al., (2006). Utilizing nitrogen oxide (NOx), nitrogen dioxide (NO2), and ozone (O3) hourly mean concentration data, a method was developed for determining the principal NO2 percentage from vehicle exhausts in London. A median primary NO2 fraction of 10.6% was discovered by them, and this accounted for almost 21% of the NO2 concentration that was detected at roadside locations. Carslaw et al., (2005)

To assess the vulnerability caused by air pollution at different sites. To improve the quality of the air, they suggested a number of actions, including replacing outdated cars, changing the composition of diesel fuel, introducing LPG and CNG, improving infrastructure, and implementing radical traffic control techniques into practice. Ghose et al., (2004) Measured the hourly concentrations of air pollutants in the ambient air between April and May 2000 from 7:00 to 24:00 hours using a mobile station. They reported that PM10 levels exceeded WHO permissible limits in all cities, while SOx, NOx, and CO concentrations were within the limits. Specifically, in Islamabad, PM10 was measured at 520 µg/m³, SO2 at 28 ppb, CO at 1.55 ppm, NO2 at 148 ppb, and O3 at 10 ppb. PAK-EPA/JICA (2001).

Analyzed airborne particulate matter from Birmingham, UK, Coimbra, Portugal, and Lahore, Pakistan. Significant variations in source contributions were observed; in Lahore, soil dust accounted for 62% of the total suspended particulate matter, while contributions from road traffic emissions were significantly lower in Birmingham and

Coimbra (Harrison et al., 1997)

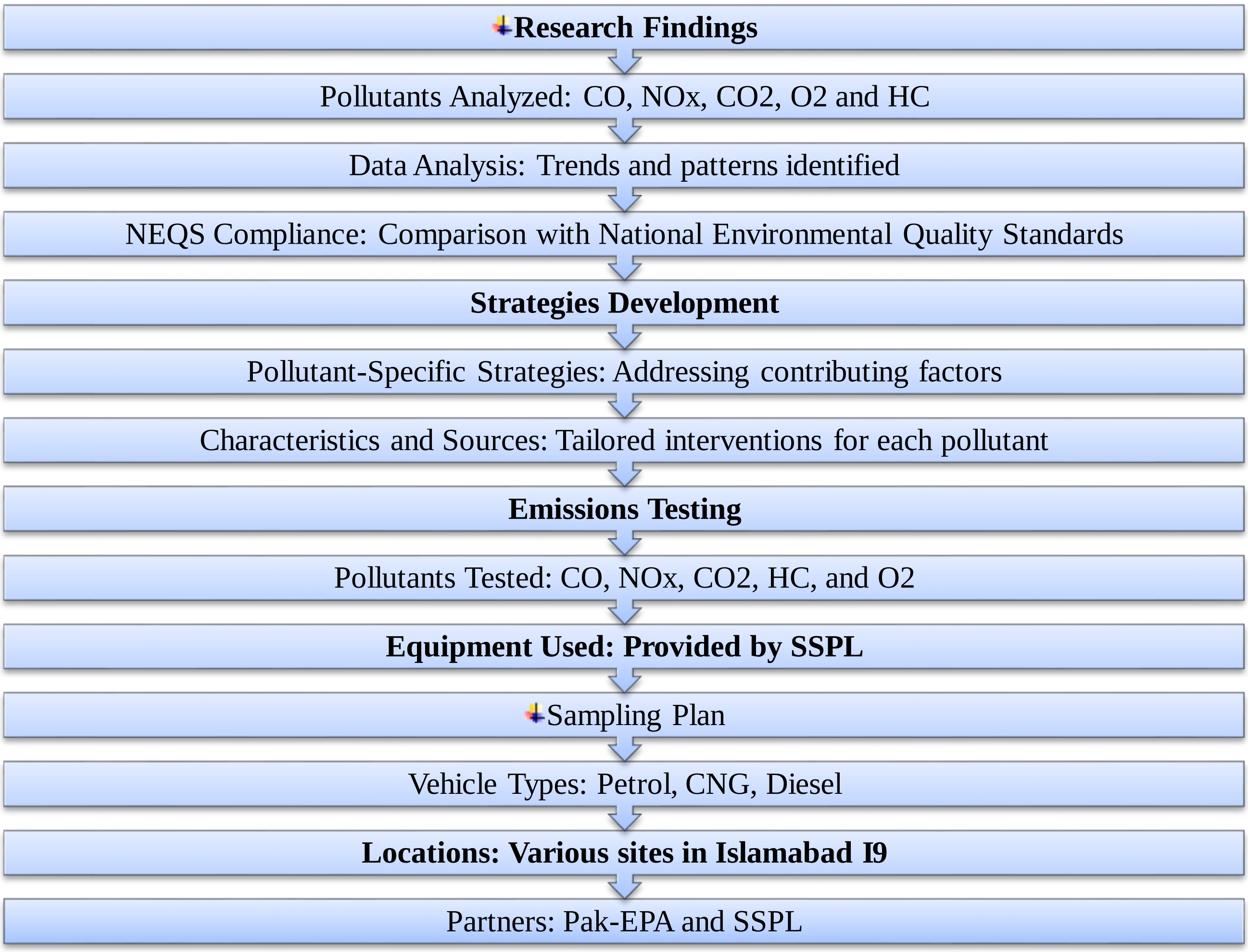
Measuring the levels of polycyclic aromatic hydrocarbons (PAH) in air samples from Lahore, Pakistan, and Birmingham, UK, as well as surface and road dust. Despite higher air concentrations in Lahore, they discovered that the levels of PAHs in soil there were lower than in Birmingham. This was attributed to Pakistan's climate, which enhances photo-oxidation and volatilization. A strong correlation was observed between PAHs in airborne particles and soils in Lahore (Smith et al., 1995).

CHAPTER 2
MATERIAL AND METHODS

2.1. Context and Background

Keeping in view the aims, objectives and scope of the study, the following methodology was adopted to undertake the study.

Table 2.1. Methodology layout



Research Findings

Pollutants Analyzed: CO, NOx, CO2, O2 and HC

Data Analysis: Trends and patterns identified

NEQS Compliance: Comparison with National Environmental Quality Standards

Strategies Development

Pollutant-Specific Strategies: Addressing contributing factors

Characteristics and Sources: Tailored interventions for each pollutant

Emissions Testing

Pollutants Tested: CO, NOx, CO2, HC, and O2

Equipment Used: Provided by SSPL

Sampling Plan

Vehicle Types: Petrol, CNG, Diesel

Locations: Various sites in Islamabad I9

Partners: Pak-EPA and SSPL

2.2. Sourcing from Departments

To align with the research scope, we identified relevant departments and stakeholders in the city directly or indirectly involved in environmental issues and enforcement. Key entities such as Pak-EPA, SSPL (Steinol Solutions Pvt Ltd), and National Transport and Research Centre (NTRC) were recognized. Access to these entities was facilitated after completing the necessary documentation procedures.

Table 2.2. Details of sourced departments

PAK-EPA
As an executive agency under the Ministry of Climate Change, the Pakistan Environmental Protection Agency (Pak-EPA) is in charge of enforcing rules established from parliamentary laws in order to protect the environment and public health.
Key Roles in the Present Study:
• Provision of instruments
• Access to laboratories
• Provision of technical assistance

STEINOL SOLUTIONS PVT LTD (SSPL)
Steinol Solutions Pvt Ltd (SSPL) specializes in conducting emission sampling and analysis procedures tailored to comply with Environmental Protection Agency (EPA) Pakistan standards. They employ state-of-the-art exhaust emission analyzers, sound level meters, and expert personnel for accurate exhaust emissions testing.
Key Role in the Present Study:
• Utilization of advanced emission analyzers
• Measurement of pollutants including CO, NOx, CO_2, HC, and O2 emitted from vehicle exhausts

2.3. Review of Published Literature

Various documents including published reports, research papers, and newspaper articles were gathered pertaining to air pollution, degradation of air quality in Islamabad, vehicular emissions, and related topics. A variety of materials were reviewed and documented. Each citation is referenced in Chapter 6 of the References section.

2.4. Development of Baseline Data

2.4.1. Sampling sites identification

Islamabad, Pakistan's capital, is situated on the Potohar Plateau in the northwestern part of the country. Although historically part of the Punjab region and the North-West Frontier Province, it is now designated as Islamabad Capital Territory. The city is located at coordinates 33°40′N 73°10′E and has a population of approximately 601,600 residents. Five specific locations in Islamabad were chosen based on traffic volume, as illustrated in Figure 2.2

Table 2.3. Location of sampling points

Sector	**Sampling Point**	**Description**
I-9	I-9/1	Specific sector with residential and commercial buildings, assessing localized emissions
I-10	I-10 Markaz	Central commercial area with shops and offices, focusing on emissions from commercial activities.
I-9	I-9/4 .	Zone with diverse traffic patterns and emissions sources including HDV's
I-10	I-10/3 Industrial Area	Industrial sector hosting manufacturing units, monitoring emissions from industrial processes
I-10/2	I-10/2 Residential Area	Residential zone I-10, examining emissions from residential sources and local traffic.

These sampling points provide an overview of air quality and emissions characteristics within the **I-9 and I-10 sectors** of Islamabad

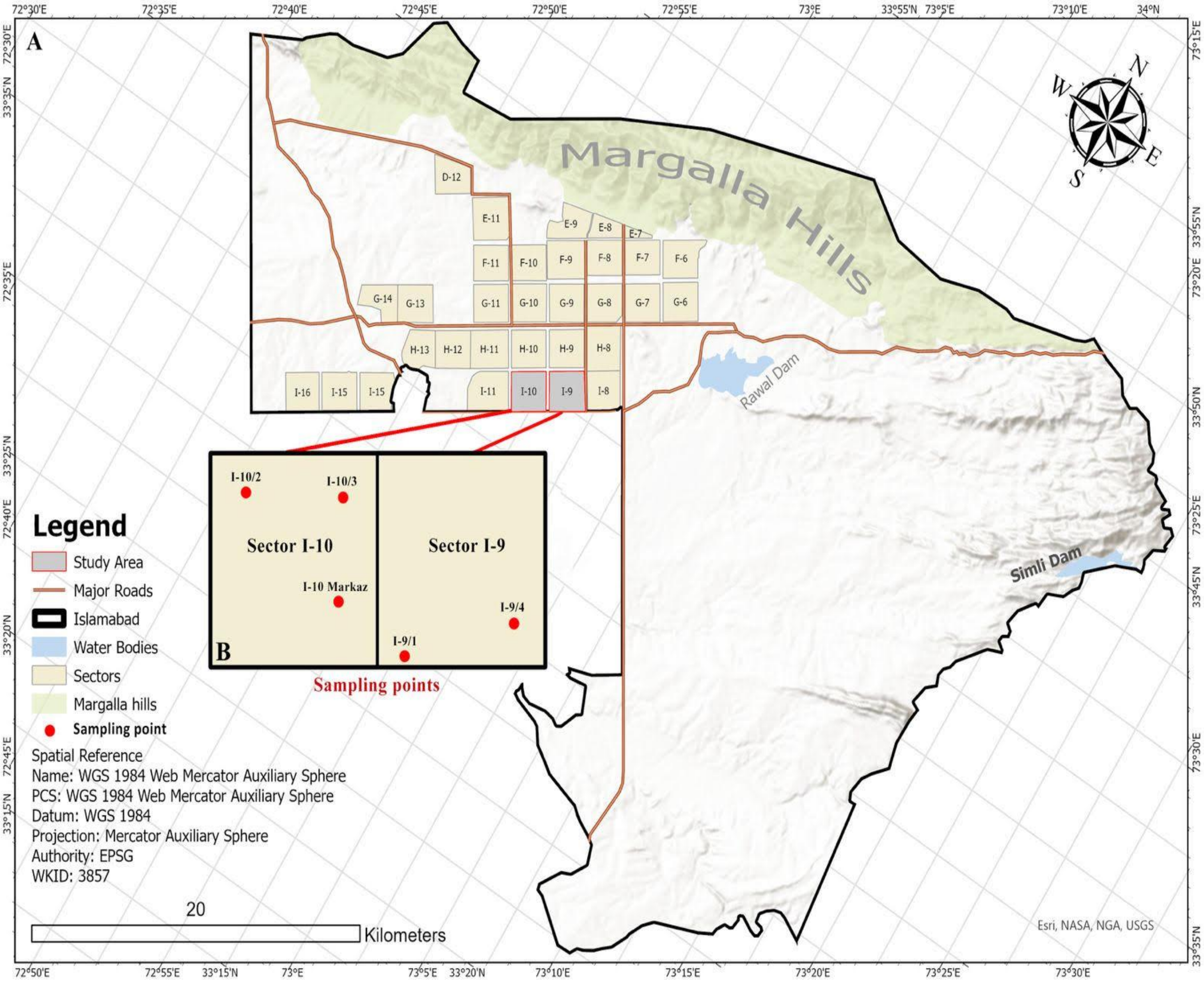


Figure 2.1. Map of Sampling locations (Using ArcGIS)

2.4.2. Vehicles tested

Vehicles were classified based on fuel type into three categories as.

- Petrol
- Diesel
- CNG

2.4.3. Number of vehicles tested

In Islamabad, we tested **300** vehicles across **Five** locations, with 20 vehicles from each of the three fuel types monitored at each location, totaling 60 vehicles per location (60x5= 300).

2.4 Analysis process

Vehicles were selected randomly from the roads with assistance from the SPPL team. Upon obtaining permission from drivers, gas sampling pumps were employed to analyze gases present in the vehicular exhaust.

2.4.1 Analysis time

Each analysis took approximately 15-20 minutes to completely analyze vehicle exhaust emissions.

2.4.2 Information recorded

- Vehicle type
- Vehicle registration number
- Model number
- Fuel source
- Exhaust gases emissions

2.4.3 Parameters tested

Pollutants that were analyzed for the study are included as:

i. Hydrocarbons
ii. CO
iii. Carbon dioxide (CO_2)
iv. NO_X
v. O_2
vi. Smoke particularly for Diesel Vehicle

2.5 Reference Method Used for Testing Emission

Emissions /pollution monitoring was done based on the parameters recorded in table 2.4

Table 2.4. Testing methods

S/No	Parameter	Method Used
1.	Hydrocarbons	1500-E4500 COMBUSTION ANALYZER/ MULTI GAS ANALYZER
2.	CO	1500-E4500 COMBUSTION ANALYZER/ MULTI GAS ANALYZER
3.	CO_2	1500-E4500 COMBUSTION ANALYZER/ MULTI GAS ANALYZER
4.	O_2	1500-E4500 COMBUSTION ANALYZER/ MULTI GAS ANALYZER
5.	NO_X	1500-E4500 COMBUSTION ANALYZER/ MULTI GAS ANALYZER
6.	Smoke	1500-E4500 COMBUSTION ANALYZER

Figure.2.2a. Combustion Analyzer

The 1500-E4500 combustion analyzer operates by sampling gases emitted from combustion processes, typically through a probe inserted into the exhaust stack or flue gas outlet. These gases are then drawn into the analyzer, where they pass through sensors and detectors that measure the concentration of specific gases such as oxygen (O2), carbon monoxide (CO), carbon dioxide (CO_2), and nitrogen oxides (NOx). Once the gases are analyzed, the analyzer processes the data obtained from the sensors and calculates the concentrations of each gas component in the sample.

Figure 2.2b. Combustion Analyzer working principle.

Using the S380 Multi Gas Analyzer for Vehicular Emission Testing

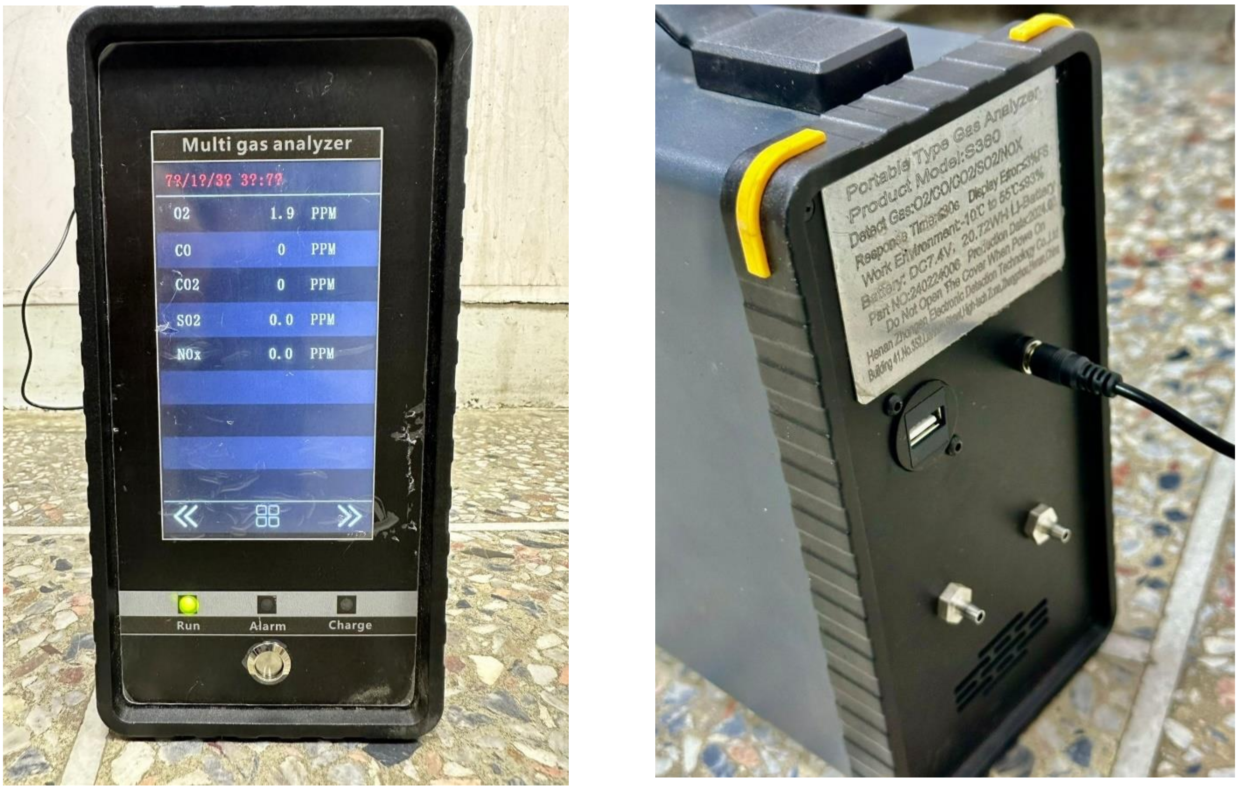


Figure 2.3 Multi Gas Analyzer equipment model S360

Prior to using the S380 Multi Gas Analyzer for vehicle emissions testing, make sure it is calibrated and that there are no leaks. Warm up the vehicle to its operating temperature. After connecting the exhaust probe to the analyzer, firmly place it within the vehicle's exhaust pipe. Turn on the analyzer, let it warm up, and select the appropriate test mode. For diesel vehicles, the S380 Multi Gas Analyzer is crucial to accurately measure pollutants like CO, NOx, CO_2, and O2 Follow the on-screen instructions to begin the test, monitor the readings, and document the results. Compare them to regulatory standards. After the test, turn off the analyzer, remove the probe, and clean and store the equipment properly. Regularly replace filters and set calibration as needed.

Figure 2.3(a) Probes used for the Multi gas Analyzer

2.5.1 Scope of Instrument

For EPA to successfully regulate exhaust emissions from small non road engines, the SSPL Company strives to establish test procedures and cycles which ensure technologies used by manufacturer not only meet the emission standards when tested over the required test procedures, but also result in a predictable emission reduction in actual use.

2.5.2 Testing Procedure:

- **Method 1**
    - **Various Warm-up**: Vehicles shall be properly warmed-up to the engine working temperature given by its manufacturer.
    - **Blow off deposit:** Before the inspection, place the gear in neutral, accelerate rapidly and immediately release the accelerator three times, to clean off the deposit in exhaust system.
    - **Recording:** Record the maximum engine speed three times; it shall be larger than maximum rated horsepower speed.

- **Method 2**
  - The inspected vehicle shall be warmed-up to the engine working temperature by its manufacturer's method (if not specified, use constant speed 50km/h) on chassis dynamometer.
  - Step the accelerator pedal to the end. Select a proper gear position and speed per maximum engine rated horsepower speed, set three test points as the following:
    - 100%±50rpm of maximum speed
    - 60%±50rpm of maximum speed
    - 40%±50rpm of maximum speed

  - Adjust the load of dynamometer to set speed. At each test point, measure until two successive smoke value measurements are not 3% different from each other (Pollution Degree). Record Dynamometer Absorbed Horsepower at each test point. If the speed is lower than 1000rpm, use 1000±50rpm as the test speed.
  - When medium diesel vehicles are inspected, at 100% of maximum rated horsepower speed on the dynamometer, the actual measured horsepower shall not be lower than 35% of maximum rated horsepower. Vehicles would be rejected if they cannot reach 35%.
  - Smoke Emission Test in Full-load Constant Speed for Diesel Vehicles e.g. under set speed, push the accelerator pedal to the end.
  - Rejected vehicles shall be re-inspected after more than 4 hours

2.6 Assessment of Emission Criteria

Various literature sources were reviewed to identify prevailing vehicular emissions standards relevant to the subject. Currently, Pakistan lacks specific emissions standards for vehicles. Therefore, European standards for vehicle categories are considered a suitable benchmark for comparison and adoption. The EURO standards establish permissible limits for the exhaust emissions of new light-duty vehicles sold within the EU and the European Economic Area (EEA) member countries. These standards aim to mitigate harmful exhaust emissions, mainly Carbon monoxide (CO), Hydrocarbons (HC), Nitrogen oxides (NOx), and Particulate Matter (PM). Euro 2 and

Euro 3 vehicle models are commonly found in Pakistan.

2.7 Organizing SSPL visit for Testing Purpose

Field visits were planned as shown in table 2.5 accompanied by SSPL staff and equipped with the above-mentioned instrument. Field visits were planned as follows:

Table 2.5. Sampling Execution planning

Day	Date	Location	Time	No. of vehicles tested
1.	05-05-24	Point 1(I-9/1)	3 hrs	14
2.	06-05-24	Point 1(1-9/1)	2 hrs	10
3.	07-05-24	Point 1(I-9/1)	4 hrs	16
4.	08-05-24	Point 1 (I-9/1)	3 hrs	20
5.	10-05-24	Point 2 (I-9/4)	3 hrs	12
6.	12-05-24	Point 2 (I-9/4)	3 hrs	14
7.	15-05-24	Point 2 (I-9/4)	4 hrs	18
8.	17-05-24	Point 2 (I-9/4)	3 hrs	14
9.	18-06-24	Point 2 (I-9/4)	3 hrs	18
10.	19-06-24	Point 3 (I-10 Markaz)	3 hrs	12
11.	20-06-24	Point 3 (I-10 Markaz)	3 hrs	12
12.	22-06-24	Point 3 (I-10 Markaz)	3 hrs	12
13.	24-06-24	Point 3 (I-10 Markaz)	4 hrs	12
14.	26-06-24	Point 3 (I-10 Markaz)	4 hrs	12
15.	27-06-24	Point 4 (1-10/2 Residential area)	5 Hrs	15
16.	31-06-24	Point 4 (1-10/2 Residential area)	3 hrs	16
17.	01-07-24	Point 4 (1-10/2 Residential area)	4 hrs	14
18.	05-07-24	Point 4 (1-10/2 Residential area)	3 hrs	15
19.	06-07-24	Point 5(1-10/3 Industrial area area)	2 hrs	15
20.	07-07-24	Point 5 (1-10/3 Industrial area area)	3 hrs	16
21.	08-07-24	Point 5 (1-10/3 Industrial area area)	2 hrs	14
22.	09-07-24	Point 5 (1-10/3 Industrial area area)	4 hrs	15

2.8 Interpretative Analysis and Reporting

The findings were analyzed considering the study's scope and objectives. Emission levels were compared against established standards, and an assessment of the overall vehicle conditions in Islamabad was conducted. Recommendations were formulated to facilitate effective management and mitigation measures accordingly.

CHAPTER 3

RESULTS AND DISCUSSION

In this chapter, the presented results are interpretations derived from categorized data, emphasizing specific details regarding tested vehicles and the levels of pollutants detected.

3.1 Information on Vehicles Tested

Throughout the monitoring phase, 300 vehicles underwent testing, encompassing cars, public transport buses, trucks, and delivery vans. These vehicles utilize a variety of fuels including CNG, petrol, and diesel. Detailed data from the field visits is available in Appendix I. The distribution of vehicles across each fuel category is presented in Figure 3.1

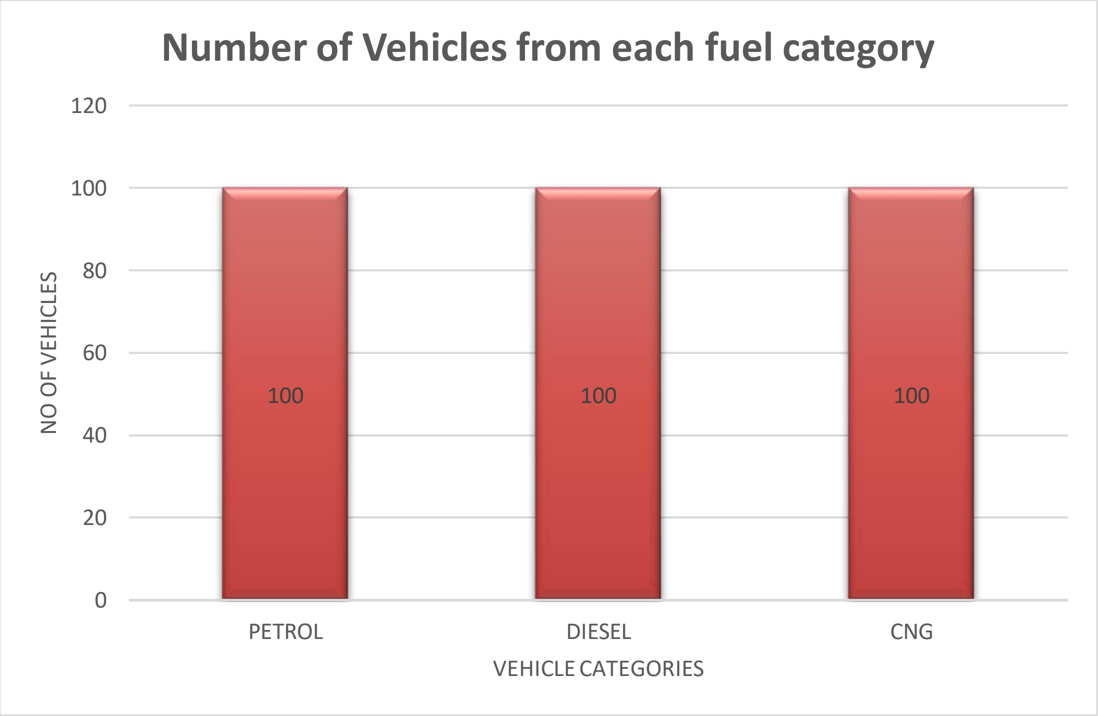


Figure 3.1 Total no. of tested vehicles.

3.2 Concentration of Pollutants

Pollutant concentrations were monitored and analyzed, with details provided for each pollutant as below:

3.2.1 CO Concentrations

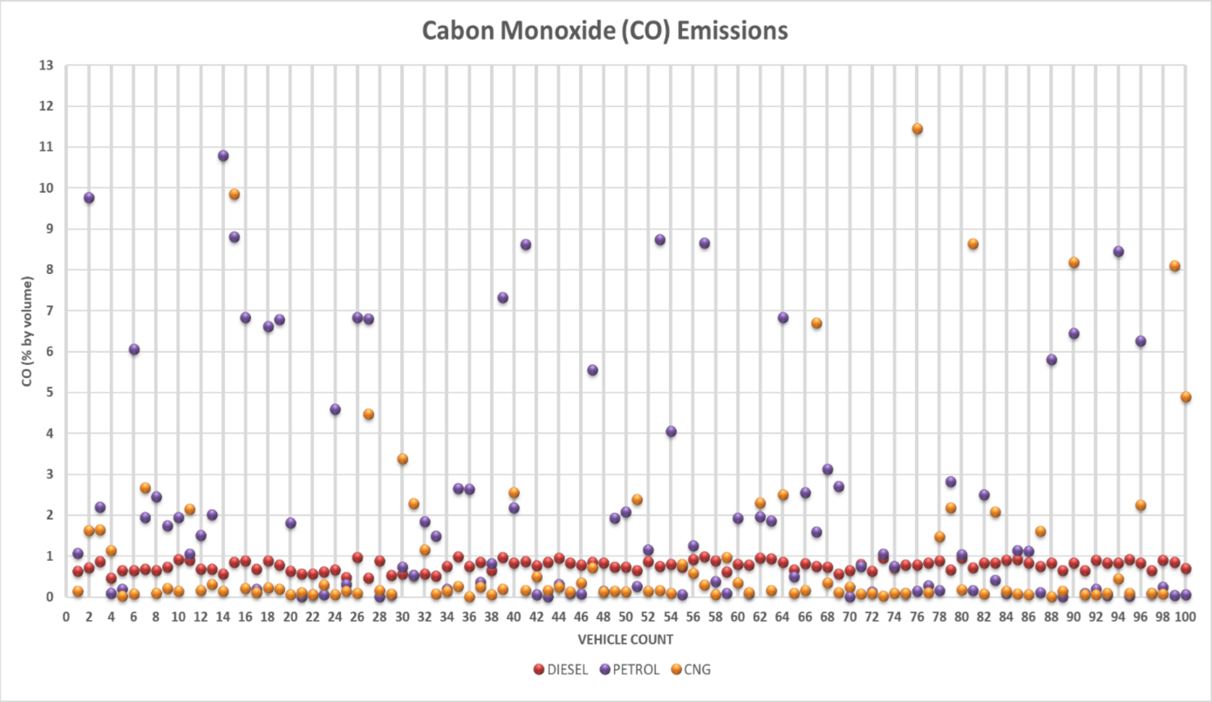


Figure 3.2 Observed CO level of Different fuel categories

Figure 3.2 depicts the carbon monoxide concentrations observed in CNG, petrol, and diesel vehicles. Petrol-fueled vehicles show the highest emissions, followed by CNG and then Diesel.

1. **Diesel (Red Dot):**

The CO concentrations for diesel vehicles appear to stay consistently low, hovering around 1% by volume or less.

This is in line with Euro 3 standards for diesel vehicles, which allow a CO limit of 0.64 g/km (~320 PPM), translating to around 1-2% volume in real-world driving conditions.

The diesel vehicles seem to meet the Euro 3 standard for CO emissions quite comfortably.

2. Petrol (Purple Dot):

CO concentrations for petrol vehicles show much larger spikes, reaching up to 7-9% in some cases.

Under Euro 2 standards, petrol vehicles are allowed 2.2 g/km (~1100 PPM), which equates to about 5-6% CO by volume.

The spikes in petrol vehicles suggest that several vehicles exceed the Euro 2 CO limits, especially at higher concentrations above 6%.

3. CNG (Orange Dot):

The CNG vehicles show significant fluctuations, with CO concentrations peaking at 10-12% by volume.

For CNG under Euro 2, the CO limit is 3.0 g/km (~1500 PPM), translating to around 5-6% by volume.

Many CNG vehicles in this graph are emitting CO levels much higher than the Euro 2 standard, indicating poor emissions control or potentially malfunctioning systems.

Diesel vehicles seem to comply with Euro 3 standards in terms of CO emissions, with consistently low values. Petrol vehicles show more variability, with some emissions exceeding the Euro 2 limit. CNG vehicles appear to have the highest CO emissions, with many exceeding the allowed Euro 2 standard, potentially due to inefficient combustion or poorly maintained engines. The Graph indicates that, while diesel vehicles are generally meeting emissions standards, there is a significant compliance issue with petrol and CNG vehicles in terms of CO emissions. Carbon monoxide (CO) poses significant health risks, with prolonged exposure potentially causing severe damage to the respiratory system and lungs (Levy, 2015). Long-term exposure has also been associated with adverse effects on the neurological system (Evans et al., 2014). Acute symptoms include headaches, dizziness, vomiting, and nausea

3.2.2 CO₂ Concentration

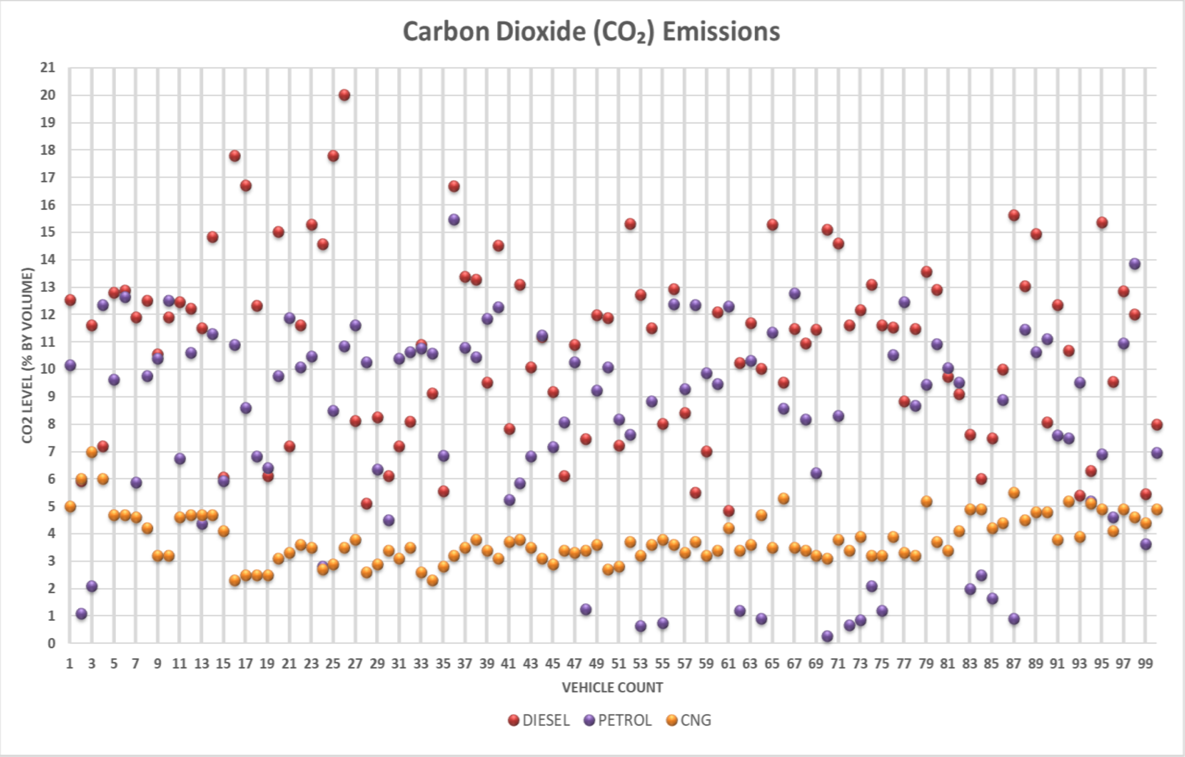


Figure 3.3 Observed CO2 level of Different fuel categories

Figure 3.3 displays the recorded levels of CO₂ derived from vehicle testing data. Figure X illustrates the CO₂ emissions levels (measured in percentage by volume) from different types of vehicles (Diesel, Petrol, and CNG) over a series vehicle counts. CO₂ emissions are not regulated under Euro 2 or Euro 3 standards. Instead, they are addressed through separate fuel efficiency regulations and overall climate policies aimed at reducing greenhouse gas emissions. Diesel and Petrol vehicles show fluctuating and often high CO₂ emissions, which may indicate they do not meet the desired fuel efficiency goals that Euro 2 and Euro 3 aims to achieve. CNG vehicles display far lower and stable CO₂ emissions, suggesting they are more likely to be in compliance with Euro 2 standards, indirectly supporting environmental goals.

1. Diesel Vehicles (Red Dot):

Diesel vehicles generally exhibit the highest variation in CO₂ emissions, fluctuating significantly between approximately 8% and 20%. Peaks in emissions are observed consistently, especially above 10%.

2. Petrol Vehicles (Purple Dot):

Petrol vehicles show more variability in emissions compared to CNG but less so than Diesel vehicles. The emission levels fluctuate between roughly 6% and 17%. There is no consistent trend, but values seem to fall more frequently within the 8–12% range.

3. CNG Vehicles (Orange Dot):

CNG vehicles exhibit the lowest CO_2 emissions, with values mostly ranging between 4% and 6%. This emission level is relatively stable compared to the other fuel types, with minimal fluctuation.

This variability suggests that higher CO_2 levels in vehicle exhaust emissions can indicate optimal performance with complete combustion of fuels, predominantly composed of organic molecules, primarily hydrocarbons (Kakaee et al., 2014). From an environmental perspective, CO_2 is a potent greenhouse gas. The significant release of CO_2 from vehicles contributes significantly to global warming and urban air quality issues such as photochemical smog, which adversely affects human health (GFEI, 2017). Health impacts include headaches, dizziness, restlessness, tingling or pins and needles sensation, choking, sweating, fatigue, elevated pulse rate, high blood pressure, and in severe cases, coma, asphyxia, and convulsions (Krzyzanowski et al., 2005).

3.2.3 NOx Concentrations

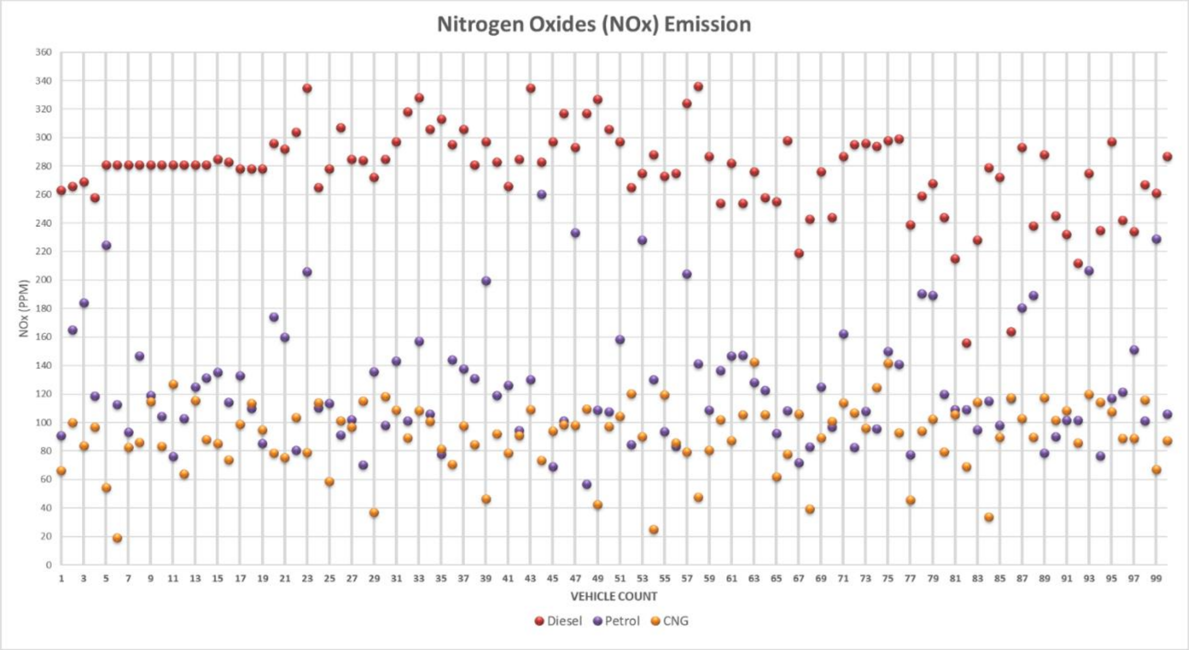


Figure 3.4 Observed Nox level of Different fuel categories

Factors contributing to nitrogen oxide emissions from automobiles include advanced injection timings, increased compression ratio, turbocharging, and the octane number of fuels (Mukerjee, 1988).

Diesel Vehicles (Red Dot):

Diesel vehicles consistently show the highest NOx emissions, with concentrations typically between 260 PPM and 340 PPM. The NOx levels remain relatively stable with small fluctuations, but they are always higher than those of petrol or CNG vehicles.

Petrol Vehicles (Purple Dot):

Petrol vehicles exhibit moderate NOx emissions, with values fluctuating between 60 PPM and 220 PPM. Graphs shows significant variation in NOx concentrations for petrol vehicles, with multiple spikes reaching higher levels.

CNG Vehicles (Orange Dot):

CNG vehicles show the lowest NOx emissions, with most values fluctuating between 40 PPM and 120 PPM, and occasional peaks around 160 PPM. While there is some variation, the general trend for CNG vehicles remains lower than both diesel and petrol. Most of the Diesel vehicles in the dataset are well above acceptable NOx limits for Euro 3. Petrol vehicles barely comply with Euro 2 standards. CNG vehicles appear to perform the best in terms of NOx emissions and are most likely to meet Euro 2 standards, though some peaks should be monitored for potential non-compliance.

Nitrogen oxides are potent greenhouse gases, with nitrous oxide having a global warming potential of 310 CO_2 equivalents (IPCC, 2007). Health impacts associated with nitrogen oxides include severe irritation, skin burning, and inflammation of the airways (Schurmann et al., 2007). These gases also react with other pollutants, contributing to the formation of secondary air pollutants (Ravishankara et al., 2009).

NOx are formed throughout the combustion chamber of engine during combustion process due to reaction of atomic oxygen and Nitrogen. The reaction is very dependent on the temperature. In Petrol engines the dominant component of NOx is NO. Nitric oxide is generally not considered hazardous to health at typical ambient concentrations, but nitrogen dioxide can be (Erisman et al., 2013; Skalska et al., 2010). Nitrogen dioxide and nitric oxide together are collectively referred to as nitrogen oxides (NOx).

For internal combustion vehicular engines. The most significant reaction for production of NO (Nitric oxide) is the Zeldovich Mechanism. Three Chemical Equations which form the extended Zeldovich reaction

$$\mathrm{O + N_2 \rightarrow NO + N}$$

$$\mathrm{N + O_2 \rightarrow NO + O}$$

$$\mathrm{N + OH \rightarrow NO + H}$$

Further reactions of NO to form NO_2

$$\mathrm{NO + H_2O \rightarrow NO_2 + H_2}$$

$$\mathrm{NO + O_2 \rightarrow NO_2 + O}$$

3.2.4 HC Concentration

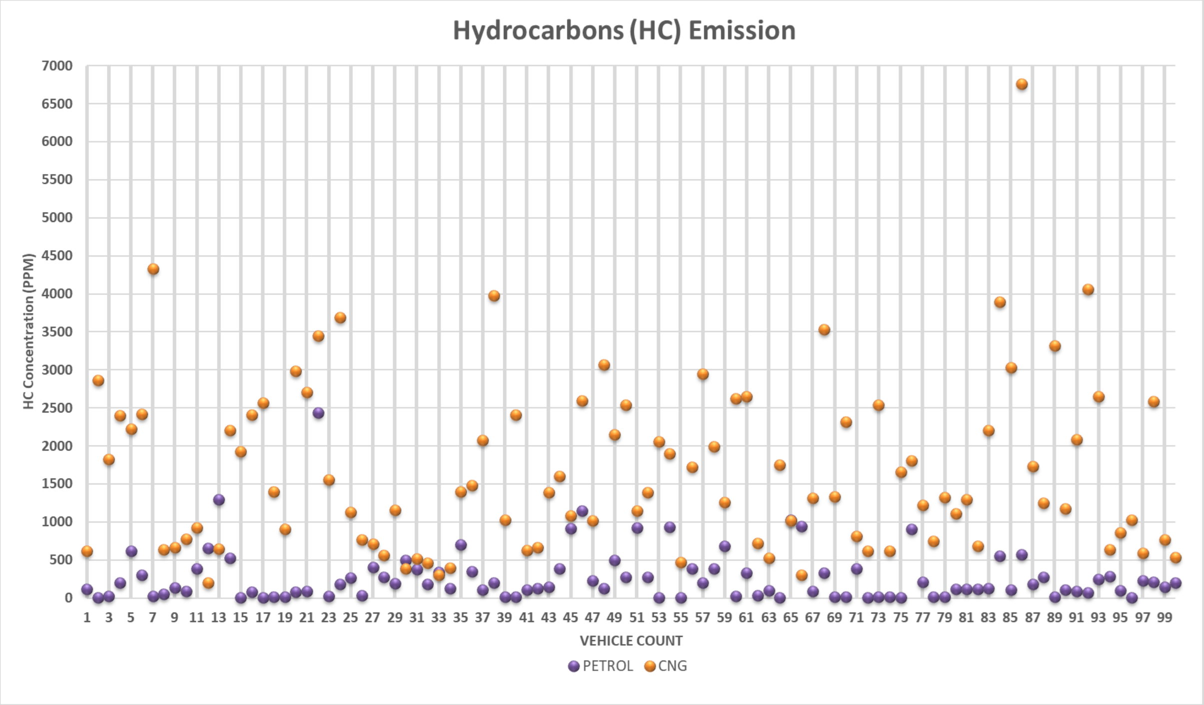


Figure 3.5 Observed HC level of Different fuel categories

This figure shows the "HC Concentration" (in PPM - Parts Per Million) plotted against "Vehicle Count" for two different types of vehicles: Petrol and CNG.

CNG Vehicles:

The Orange Dot represents the HC (Hydrocarbon) concentration from CNG vehicles. It shows significant variation in hydrocarbon emissions, with concentrations spiking as high as 6000 PPM. The graph shows a frequent fluctuation in the HC levels, with notable peaks and dips throughout the vehicle count

Petrol Vehicles:

The purple line represents the HC concentration from petrol vehicles. Petrol vehicles seem to perform much better in terms of HC emissions compared to CNG vehicles in this data set. Petrol vehicles generally have much lower HC concentrations compared to CNG, with most of the values remaining under 1000 PPM. Unlike CNG, petrol vehicles have a more stable and lower emission trend, with fewer significant peaks.

CNG vehicles tend to emit more hydrocarbons with greater variability compared to petrol vehicles, which consistently show lower HC emissions. Based on the Euro 2 standards, CNG vehicles are far above acceptable limits, while petrol vehicles might still need to reduce emissions to comply with the stricter Euro 3 standards.

Regular tuning by vehicle owners can further reduce these levels to meet standard limits, unlike CNG-based vehicles where HC levels may exceed 1500 ppm. This may be due to maladjustment and improper regulation of gas in bi-fuel system. Hydrocarbon emissions from diesel-based vehicles were not monitored due to their minimal impact. Hydrocarbons indicate inefficient combustion in internal combustion engines, where vaporized unburned fuel or partially burned fuel products exit the combustion chamber through the exhaust (Springer, 2012).

Global concerns about HC concentrations are rising due to their contribution to the formation of photochemical smog, which is linked to irritation, choking, and eye irritation. Additionally, HC emissions reduce sunlight reaching the surface, leading to reduced visibility and affecting photosynthesis processes (Abdel et al., 2016).

3.2.5 Oxygen

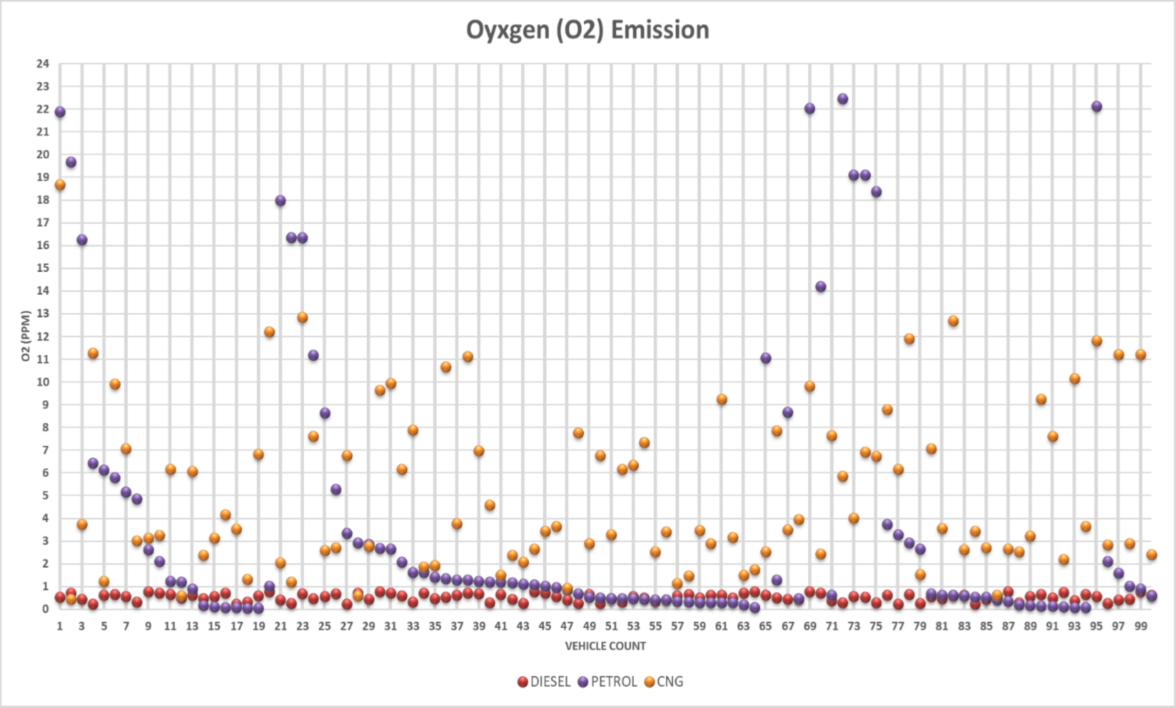


Figure 3.6 Observed O2 level of Different fuel categories

This graph shows O_2 Concentration (in PPM) plotted against Vehicle Count for three types of vehicles: Diesel, Petrol, and CNG.There are no specific limits on O_2 concentration in the Euro standards, as these standards typically focus on limiting harmful emissions such as CO, NOx, HC, and particulate matter (PM). However, O_2 concentration is indirectly related to combustion efficiency, which in turn influences these harmful emissions.

Diesel Vehicles (Red Dot):

Diesel vehicles exhibit very low O_2 concentrations, generally near 0 PPM consistently throughout the vehicle count. This indicates that diesel vehicles tend to burn oxygen completely or have minimal excess oxygen in the exhaust, which is typical for diesel combustion processes where the air-fuel mixture is lean, and oxygen is utilized efficiently.

Petrol Vehicles (Purple Dot):

Petrol vehicles show high fluctuations in O_2 concentrations, with several spikes reaching up to 22 PPM, particularly in the earlier and later portions of the vehicle count. There is a general pattern where oxygen concentrations dip to lower values between 5–10 PPM for some vehicles but spike again, indicating that petrol vehicles exhibit incomplete combustion at times, leaving excess oxygen in the exhaust.

CNG Vehicles (Orange Dot):

CNG vehicles show significant fluctuations as well, with O_2 concentrations reaching peaks as high as 10–12 PPM. However, there are moments when the O_2 concentration drops near 0 PPM. CNG vehicles exhibit a mix of complete and incomplete combustion, like petrol vehicles but with lower peak O_2 concentrations overall. The analysis of oxygen (O_2) concentrations in exhaust emissions reveals distinct patterns among diesel, petrol, and CNG vehicles. These vehicles consistently exhibit very low O_2 concentrations, close to 0 PPM, indicating efficient combustion with minimal excess oxygen. This aligns with the lean air-fuel mixture typical of diesel combustion processes. In contrast, petrol vehicles display high fluctuations in O_2 levels, with spikes reaching up to 22 PPM.

This variability suggests incomplete combustion at times, resulting in excess oxygen in the exhaust, particularly in certain segments of the vehicle count. CNG vehicles also demonstrate significant fluctuations, with O_2 concentrations peaking between 10–12 PPM but occasionally dropping near 0 PPM. This pattern indicates a combination of complete and incomplete combustion, like petrol vehicles, but with lower peak O_2 levels.

Overall, diesel vehicles are the most efficient in oxygen utilization, while petrol and CNG vehicles exhibit more variability, indicating differences in combustion efficiency.

Gasoline-powered engines combust gasoline in the presence of oxygen. Factors influencing oxygen availability and utilization in automotive engines include air temperature, altitude, engine load, and barometric pressure (Gilles, 2012). Typically, an oxygen (O2) sensor is installed to generate voltage based on a chemical reaction triggered by the gasoline-to-oxygen ratio. Most modern engines adjust fuel injections based on feedback from the O2 sensor.

If the oxygen sensor malfunctions, the engine control unit cannot accurately determine the air-fuel ratio (Hakeem et al., 2016). Consequently, engine efficiency decreases, leading to increased emissions and reduced vehicle performance.

Based on the analysis of CO, HC, NOx, O2, and CO_2 emissions from Diesel, Petrol, and CNG vehicles, we can conclude the following:

1) Diesel Vehicles:

- **CO Emissions:** Diesel vehicles consistently emit low CO, comfortably meeting Euro 3 standards.
- **HC Emissions:** Not analyzed for Diesel, but diesels emit less HC than petrol engines.
- **NOx Emissions:** Diesel vehicles show the highest NOx levels, often exceeding Euro 2 limits, which is a common issue due to the high temperatures in diesel combustion.
- **O2 Levels:** Diesel engines efficiently burn oxygen, with near-zero O2 in the exhaust, indicating a lean air-fuel mixture and efficient combustion.
- **CO_2** Emissions: Diesel vehicles show high fluctuations in CO_2 levels, suggesting variable fuel efficiency but higher CO_2 emissions than CNG vehicles. Diesel vehicles are efficient in CO and O2 emissions but struggle with high NOx and fluctuating CO_2 levels. They meet Euro 3 CO standards but fail in NOx compliance, needing attention to meet stricter emissions targets.

2) Petrol Vehicles:

- **CO Emissions:** Petrol vehicles exhibit significant variability, with some vehicles exceeding Euro 2 CO limits, particularly when emissions spike above 6%.
- **HC Emissions:** Petrol vehicles perform better than CNG, emitting much lower HC levels and staying within Euro 2/3 compliance.
- **NOx Emissions:** Petrol vehicles display moderate NOx emissions, hovering near compliance but showing occasional spikes.
- **O2 Levels:** Petrol vehicles experience high fluctuations in O2 concentration, indicating incomplete combustion and inefficiency in some cases.
- **CO_2 Emissions:** Petrol vehicles show moderate CO_2 levels, with some variability, often between 6% and 17%. Petrol vehicles have a mixed performance. While they are better than CNG in terms of HC emissions, they

occasionally fail Euro 2 CO limits and are borderline compliant for NOx emissions. Their fluctuating O2 and CO_2 levels suggest variable fuel efficiency and combustion control issues.

3) CNG Vehicles:

- **CO Emissions:** CNG vehicles exhibit higher-than-expected CO emissions, often exceeding the Euro 2 limit, due to inefficient combustion or poor maintenance.
- **HC Emissions:** CNG vehicles produce significantly higher HC emissions, indicating incomplete combustion. This pushes them far above the Euro 2 HC limits.
- **NOx Emissions:** CNG vehicles perform well in terms of NOx emissions, consistently showing lower levels than Diesel and Petrol, making them more likely to comply with Euro 2 standards.
- **O2 Levels:** CNG vehicles display moderate fluctuations in O2 concentration, though they show slightly more stability compared to petrol vehicles.
- **CO_2 Emissions:** CNG vehicles have the lowest and most stable CO_2 emissions, making them the most fuel-efficient in terms of environmental goals related to CO_2.CNG vehicles struggle with excessive CO and HC emissions but excel in terms of NOx and CO_2. Their lower NOx and CO_2 emissions make them environmentally preferable, but they require significant improvements in CO and HC control to meet Euro 2 standards.

3.2.6 Smoke Levels

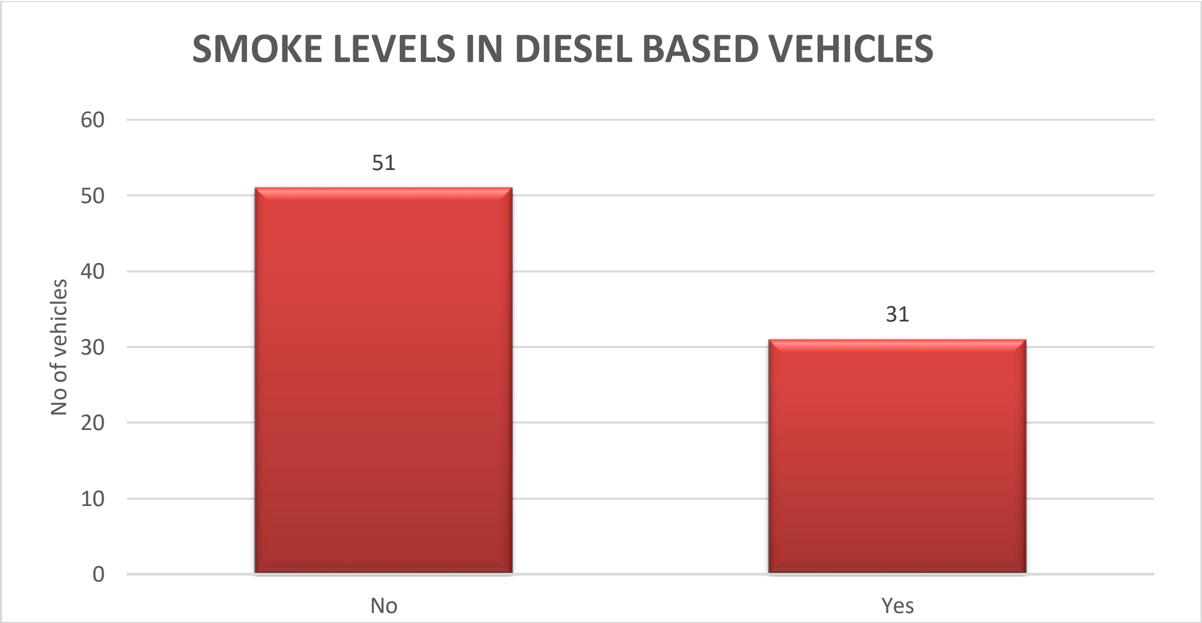


Figure 3.7 Smoke levels of diesel engines

In fig 3.7 smoke levels were assessed in 100 diesel-based vehicles, revealing that 31 vehicles exceeded the permissible limit of 40 HSU (Hartridge Smoke Units). On average, each diesel vehicle emitted 35% smoke at the monitored locations. Smoke emissions from diesel vehicles are a critical parameter due to the inherent tendency of diesel fuel to produce smoke (Dogan, 2011). Smoke opacity refers to the degree to which smoke, particulate matter, and soot obstruct light. It primarily consists of hydrocarbon particles, and higher levels indicate a greater presence of unburnt hydrocarbon particles, which can have adverse effects on the respiratory system (US-EPA, 2018).

3.3 Petrol engine pollutants analysis based on engine size

In this analysis, production of pollution is analyzed based on different engine sizes.

For this analysis, only Honda vehicles ranging from 1300 cc to 2400 cc were analyzed.

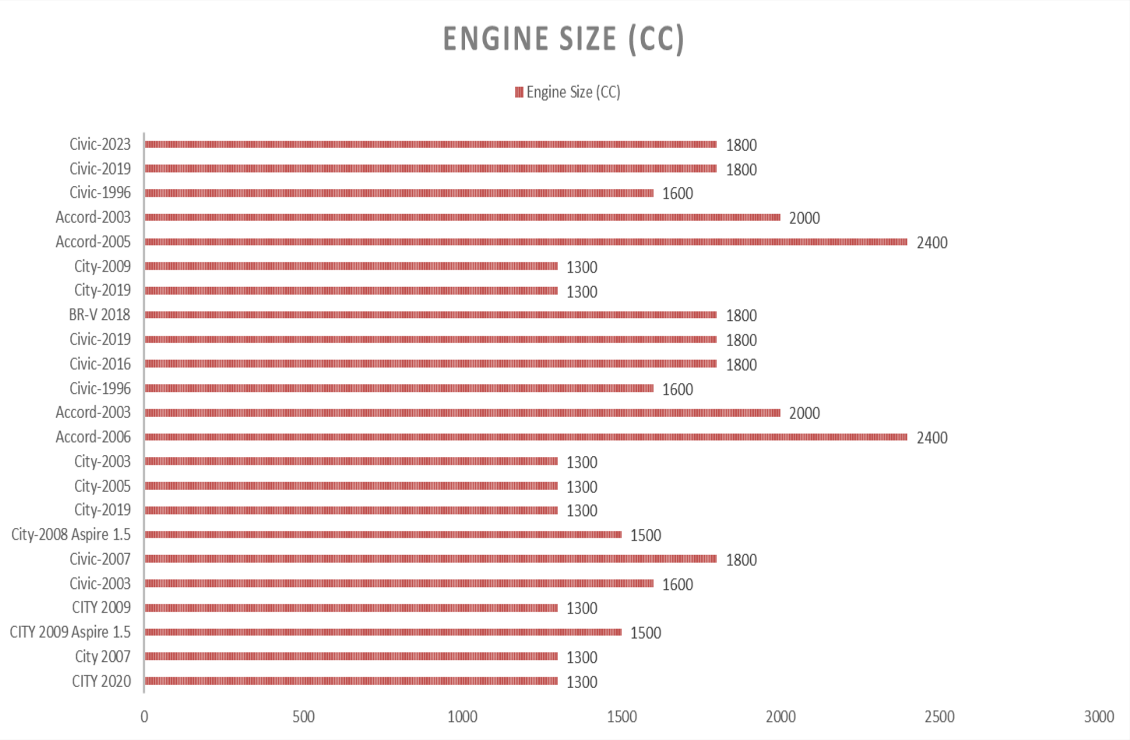


Figure 3.8 Model and engine size of Honda vehicles used in analysis

Fig 3.8 shows vehicle models and their engine sizes that were used in pie chart analysis to see the impact of engine size on emissions. Only petrol engines data is used for this analysis.

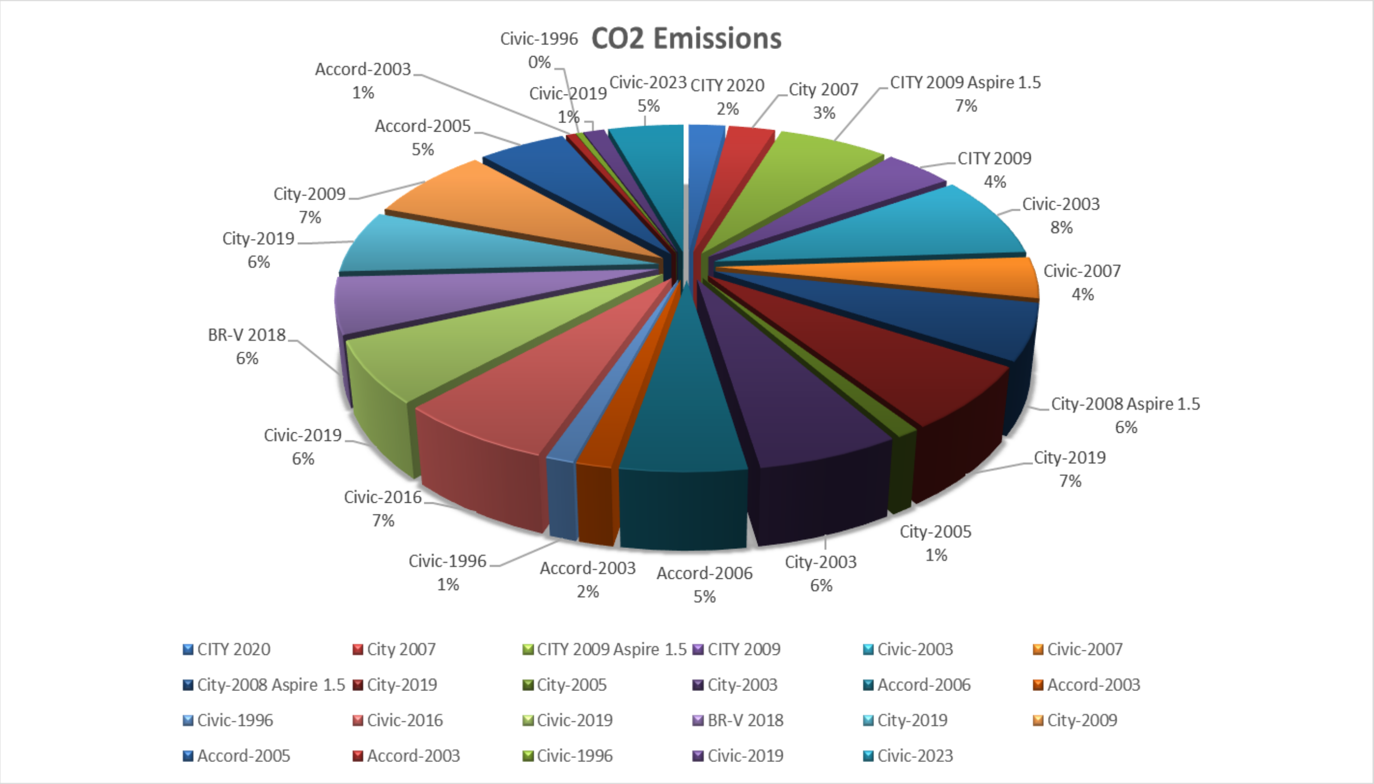


Figure 3.9. CO2 Emissions from Honda vehicles having different engine sizes

In fig 3.9 it can be observed that CO_2 emission is affected by both the engine size and age of the vehicle. In the newer models, CO_2 emissions are less while in some of the older vehicles with larger engines, i.e. Honda According, which as a 2400 cc engine has CO_2 emission level of up to 7% while Civic 2023 having engine size 1800 cc has nil CO_2 emission. This shows that newer engines are more efficient at reducing emissions while improving performance at the same time.

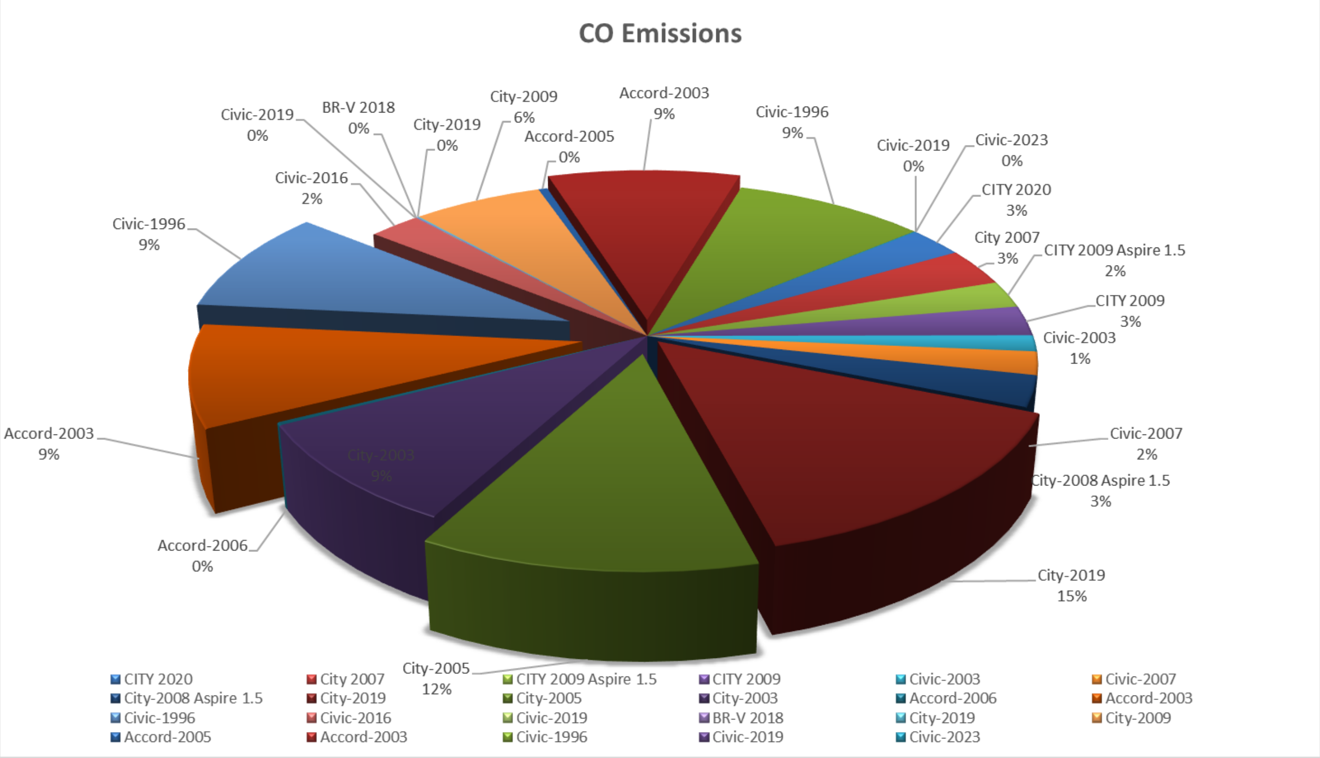


Figure 3.10. CO Emissions from Honda vehicles having different engines sizes

In fig 3.10, it is observed that CO emissions are not directly influenced by engine size nor by age of the vehicle, thus it can be concluded that car maintenance plays a significant role in controlling the CO emissions. Some of the older vehicles that are well maintained have less CO emissions than the newer models with lack of maintenance.

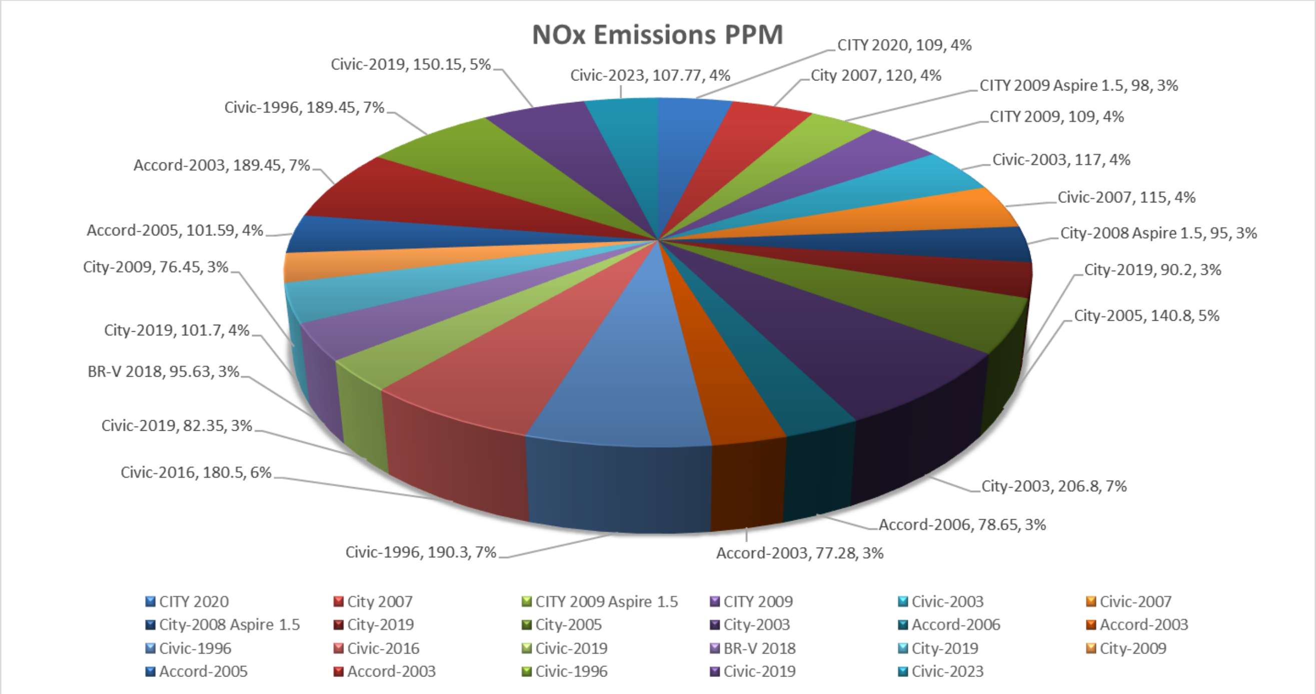


Figure 3.11. NOx Emissions from Honda vehicles having different engines sizes

In fig 3.11, it is observed that NOx emissions contribution is higher than the older models regardless of the engine size, thus it is concluded that NOx emissions are influenced by the age of the engine.

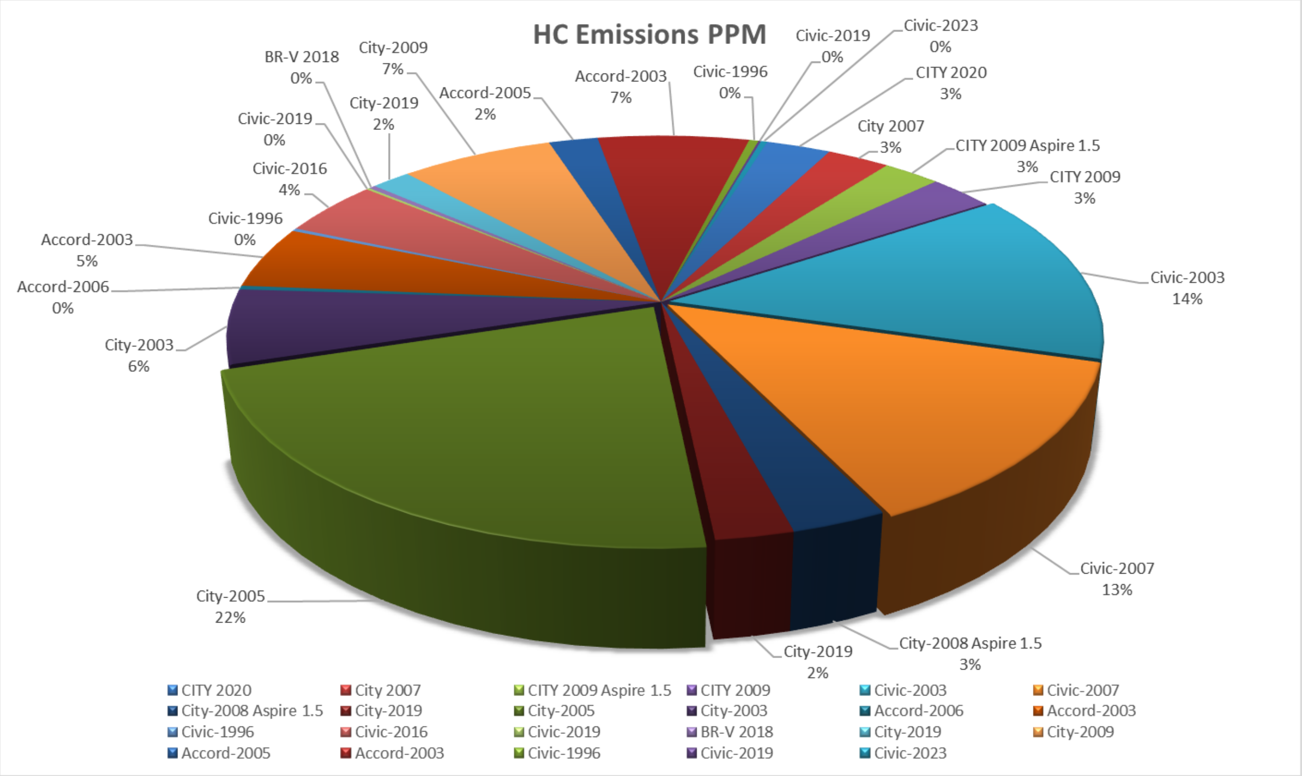


Figure 3.12. HC Emissions from Honda vehicles having different engines sizes

In fig 3.12, it is observed that HC emission contribution for certain models is much higher than the others. The Honda City 2005 model is observed to have 22% HC emissions on average which is significantly higher than the rest. Based on these observations it is concluded that engine maintenance plays a significant role in HC emissions more. Engine size: however, in case of HC emission it is observed to have little to no influence.

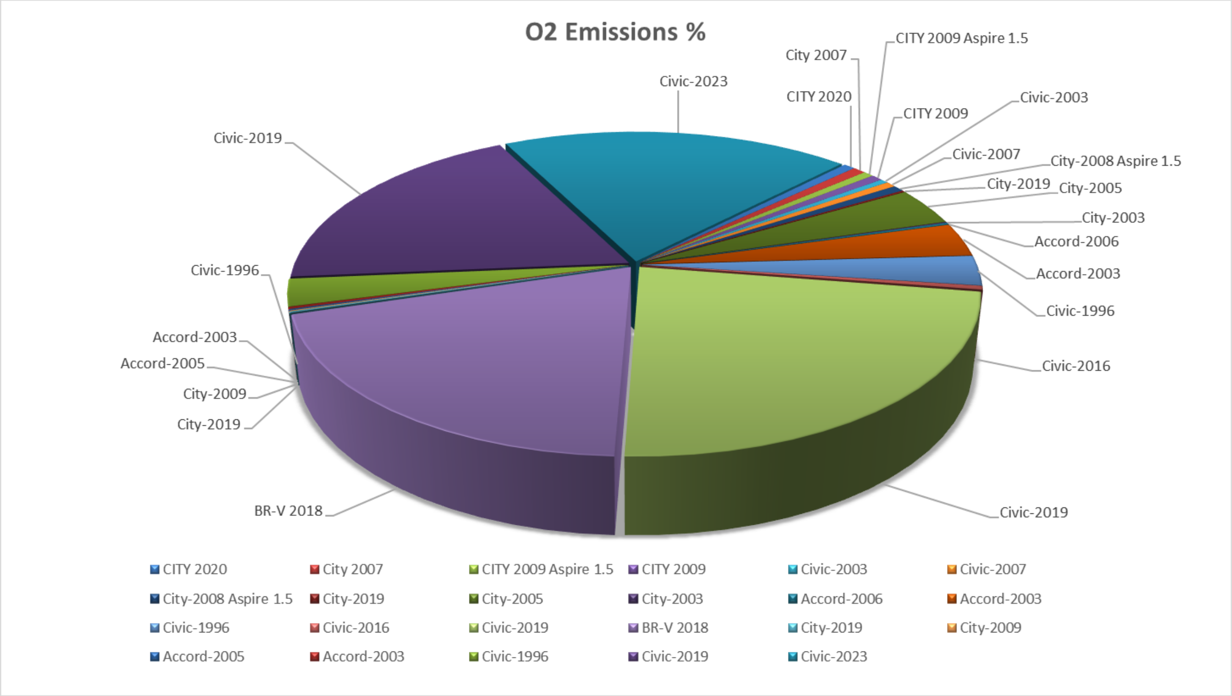


Figure 3.13. O2 Emissions from Honda vehicles having different engines sizes

Fig 3.13 shows O2 emissions, it is observed that newer models e.g. Civic 2019 and above have much higher O2 emissions as compared to older models e.g. Civic 1996 and 2003 as well as vehicles with larger engines e.g. Accord 2003 and 2005. Based on these observations it is concluded that O2 emissions are directly linked to engine designs and size, therefore in that case newer engines that are 1800cc or above have much higher O2 emissions as in case of Honda City 2019 having 1300 cc engines have comparatively much lower O2 emissions.

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3.4 Emissions comparison of vehicle brands

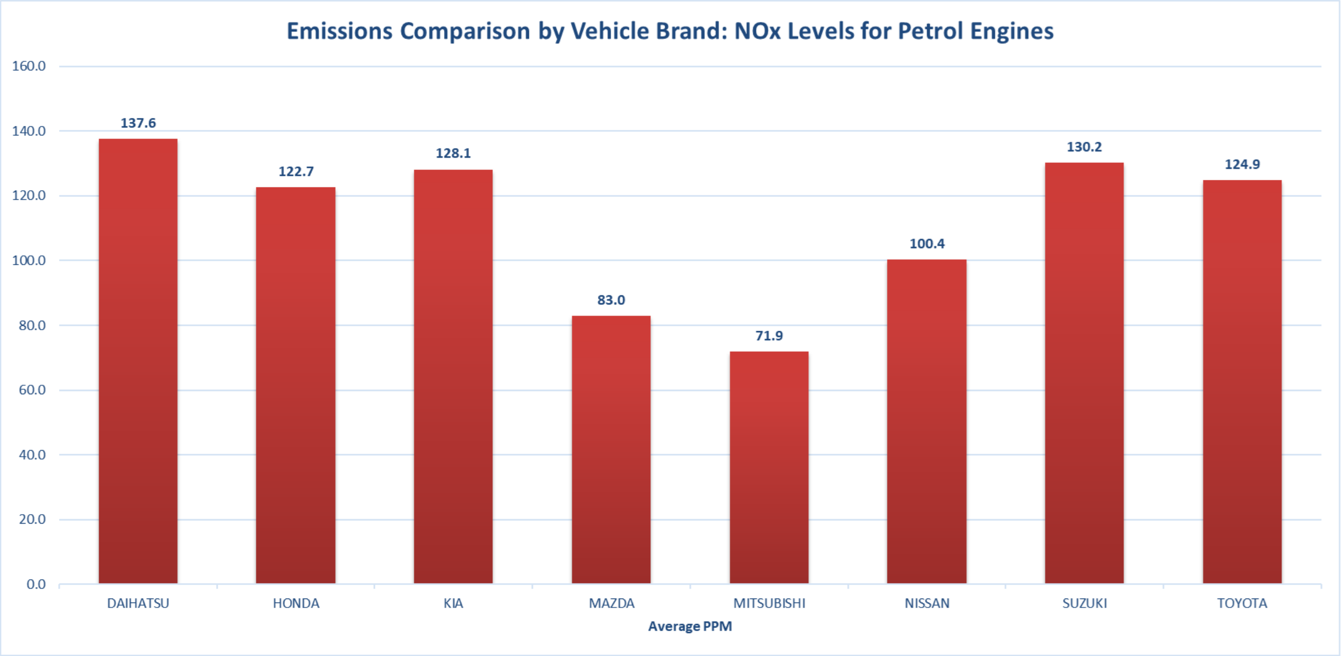
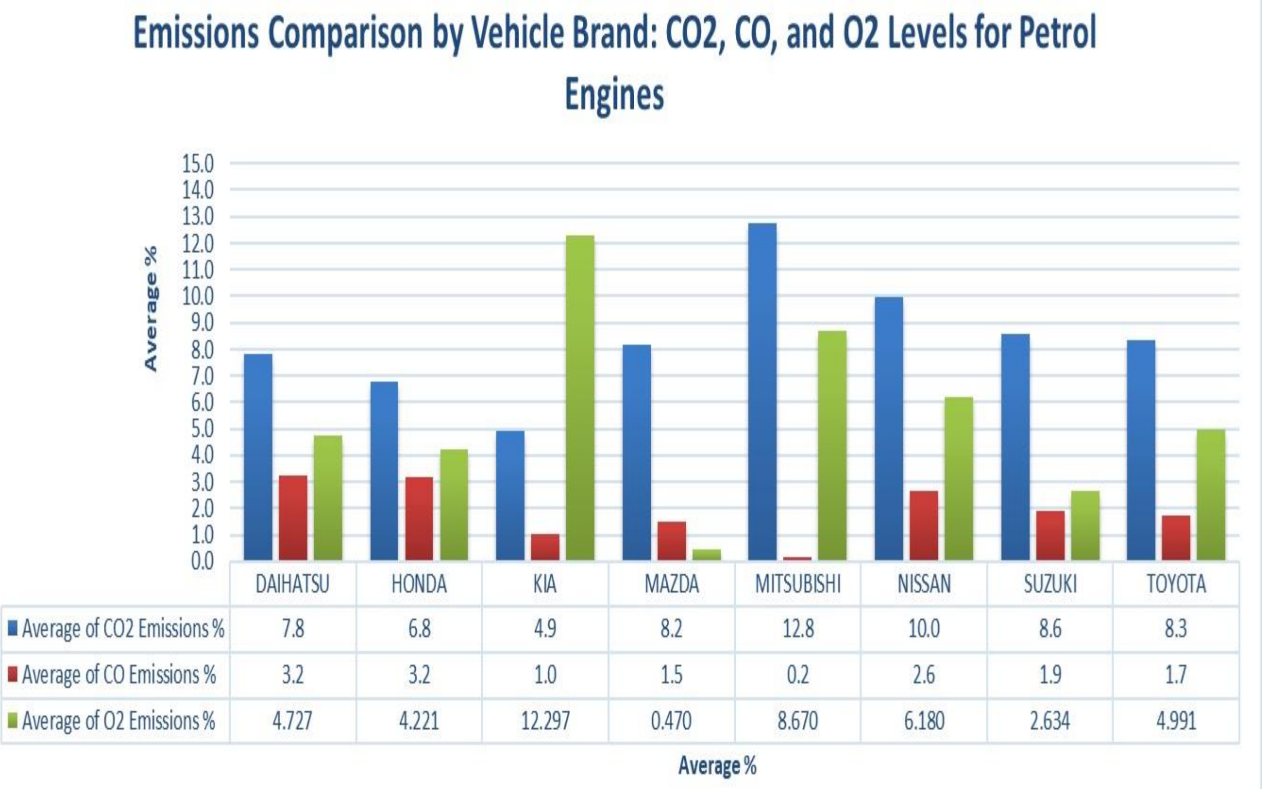


Figure 3.14 Emission Comparison by Vehicle Brand: NOx Levels for Petrol Engines

Analysis in fig 3.14 shows that nitrogen oxides emission is highest in Daihatsu vehicles followed by Suzuki, however; these values pale in comparison to the NOx emissions from diesel engines owing to their complete combustion power. Variation of nitrogen oxide emissions from petrol engines of different brands is not significant and thereby it can be concluded that the slight variation is a result of how vehicles are maintained. Engine size variation does not have immense impact on NOx production.



	DAIHATSU	HONDA	KIA	MAZDA	MITSUBISHI	NISSAN	SUZUKI	TOYOTA
🟦 Average of CO2 Emissions %	7.8	6.8	4.9	8.2	12.8	10.0	8.6	8.3
🟥 Average of CO Emissions %	3.2	3.2	1.0	1.5	0.2	2.6	1.9	1.7
🟩 Average of O2 Emissions %	4.727	4.221	12.297	0.470	8.670	6.180	2.634	4.991

Figure 3.15 Emission Comparison by Vehicle Brand: Average CO2, CO and CO2 Levels for Petrol Engines

CO_2 emission is significantly less in petrol engines than diesel engines due to incomplete combustion while CO and O2 emission are higher. Fig 3.15 shows CO_2 emission to be highest among all the different brand vehicles that were tested, reaching up to 12.8% average; followed by Nissan with an average of 10. Kia and Honda were found to have the lowest CO_2 emissions of 4.9% and 6.8% respectively. Average CO emission at highest was found to be a tie at 3.2% between Daihatsu and Honda, while the lowest emission of CO was found to be from Kia with an average of 1.0%. O2 emission at highest was found to be from Kia at an average of 12.2% while lowest was found to be 0.4% from Maza; rest of the vehicles averaged around 4-6%.

This highlights elevating CO_2 emissions from vehicles manufactured by Honda Motors and Suzuki. Commercial vehicles from Suzuki and Nissan are notably prominent in Islamabad and Rawalpindi, primarily due to the concentration of educational, governmental, and private institutions in these areas. A significant factor contributing to this trend is the continued use of older model buses by many institutions, which results in higher emissions (Clark et al., 2006). CO_2 emissions from natural gas-powered larger vehicles are lower compared to those from diesel engines (Lyford, 2003)

Emission Comparison by Vehicle Brand: HC Levels for Petrol Engines

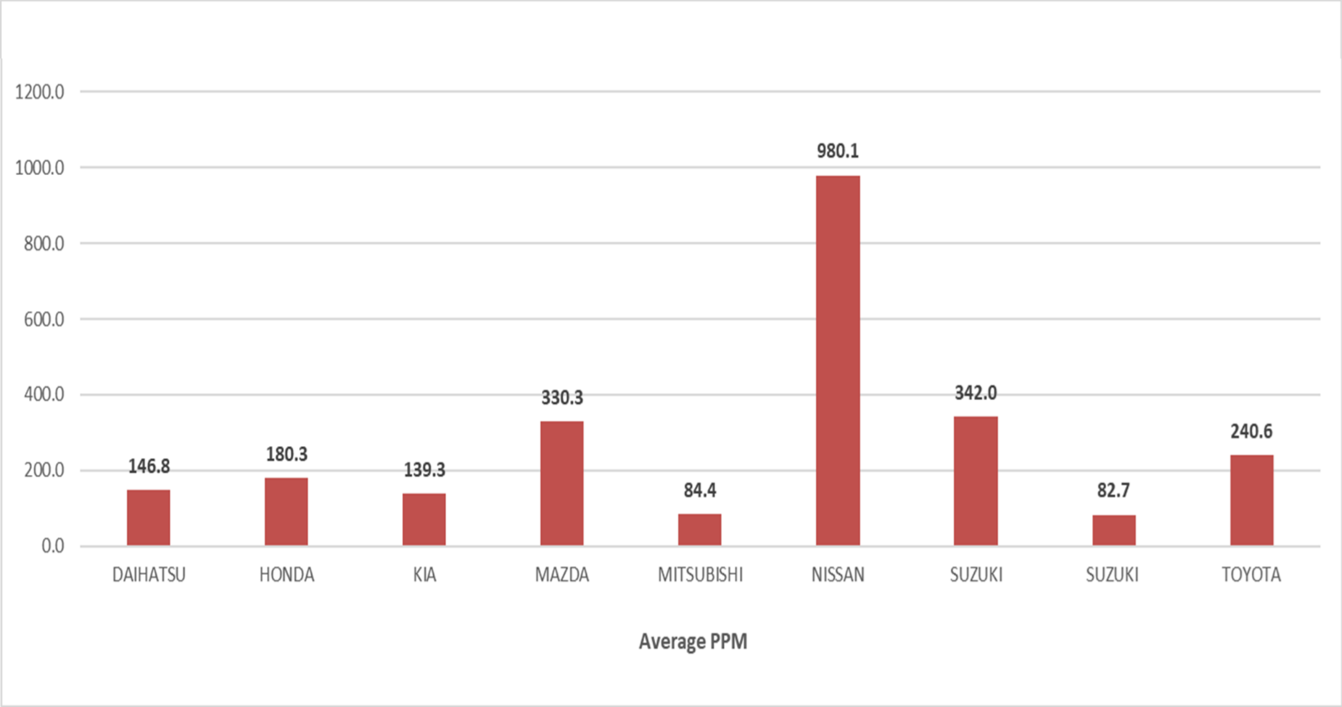


Figure 3.16 Emission Comparison by Vehicle Brand: Average HC Levels for Petrol Engines

Fig 3.16 shows average Hydrocarbons emissions of Petrol engines where Nissan is found to produce the highest HC emission at an average of 980 ppm while the lowest is found to be 84.4 ppm from Mitsubishi. It was observed that the highest HC emission of 980 ppm average from Nissan vehicles is due to their age as two vehicles tested were both 1970s models while variation between other vehicle brands is negligible as most of them are relatively newer models; however, in case of Suzuki the values are second highest due to the fact that most of the Suzuki vehicles tested were old models. It is concluded from the above analysis that vehicle age and perhaps engine design plays a significant role in HC emission as newer models with larger engines have much less than those observed in 800cc Suzuki vehicles.

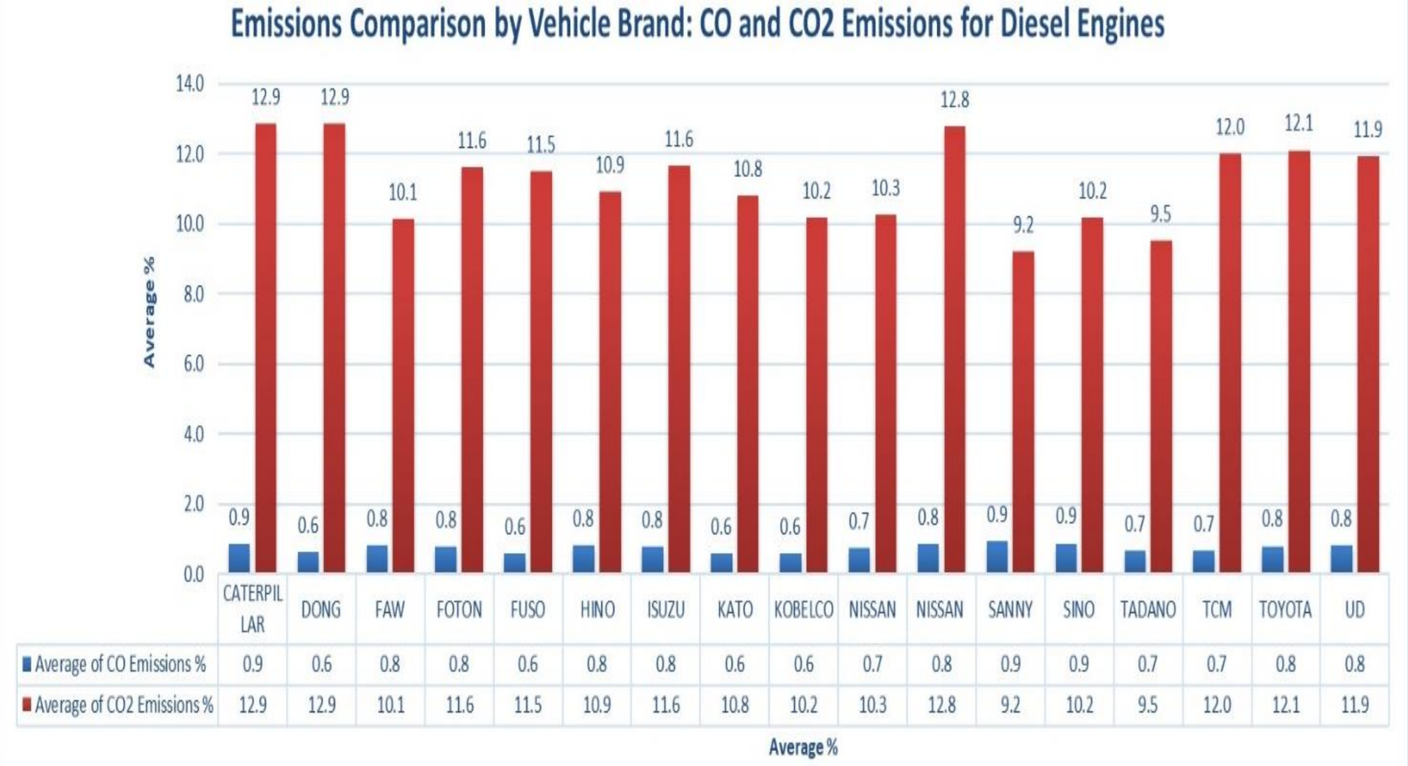


Figure 3.17 Emission Comparison by Vehicle Brand: Average CO and CO2 Levels for Diesel Engines

Fig 3.17 shows average emission of CO and CO_2 for diesel engine vehicles. It is observed that the lowest CO emissions % on average is of 0.6% which is a same for three different brands Dong, Fuso, Kato and Kobleco while the highest is observed to be 0.9% for the brand Caterpillar. There is no drastic variation between CO of different brands. CO_2 emission is similar on average across all the brands; with the highest value being 12% on average and the lowest being 9.2. It is observed that CO and CO_2 emissions levels are very close across all brands.

Nissan vehicles were noted for high carbon monoxide production in Contributing factors include vehicle overloading and road conditions. In Islamabad, Nissan vehicles such as dump trucks are frequently used in construction activities, where continuous operation without adequate maintenance significantly contributes to high emissions. The Capital Development Authority (CDA) primarily employs such vehicles for waste collection.

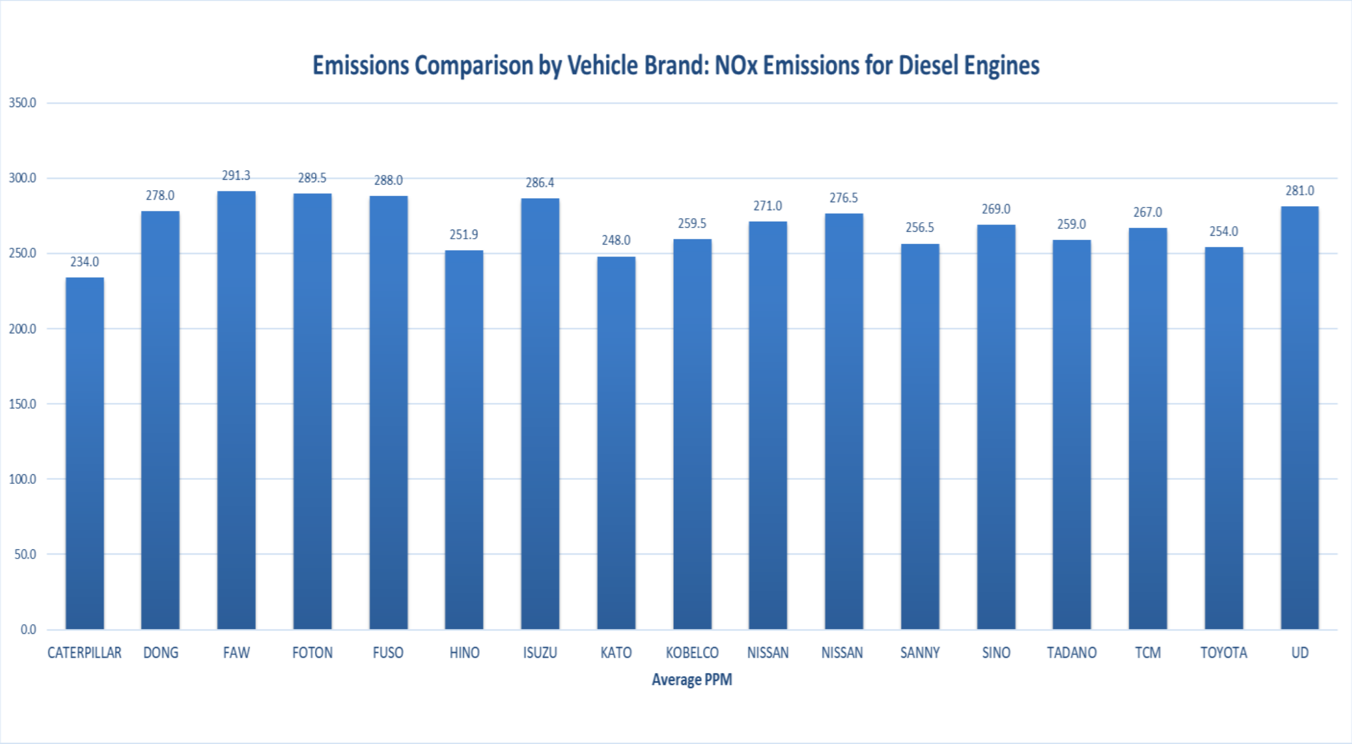


Figure 3.18 Emission Comparison by Vehicle Brand: Average NOx Levels for Diesel Engines

In fig 3.18 it is observed that the nitrogen oxide (NOx) values on average are very close across all the brand. The values are observed to be significantly higher than petrol engines as diesel engines uses high compression resulting in complete combustion.

Fig 3.19 shows NOx and HC emission averages for CNG engines. The emissions of nitrogen oxides are highest from Hyundai vehicles at 106 ppm on average while the lowest observed to be from Datsun at 83.6 ppm. HC emissions are lowest from Honda and Mitsubishi vehicles at around 950 ppm on average while the highest emitter of HC are Nissan vehicles. Toyota, Datsun, Diahatsu and Hyundai have close average emissions.

The combustion of CNG, being a dense fuel, results in significant amounts of unburned hydrocarbons. Research indicates that these unburned hydrocarbons closely resemble the composition of natural gas used in testing, with methane predominance in CNG engines (Coroller and Plassat, 2003). Honda and Suzuki vehicles are prevalent on the roads, often under high operational demands. Older models from Honda, Hyundai, Nissan, and Suzuki tend to emit more pollutants compared to newer models from other manufacturers exhibit elevated levels of hydrocarbon emissions.

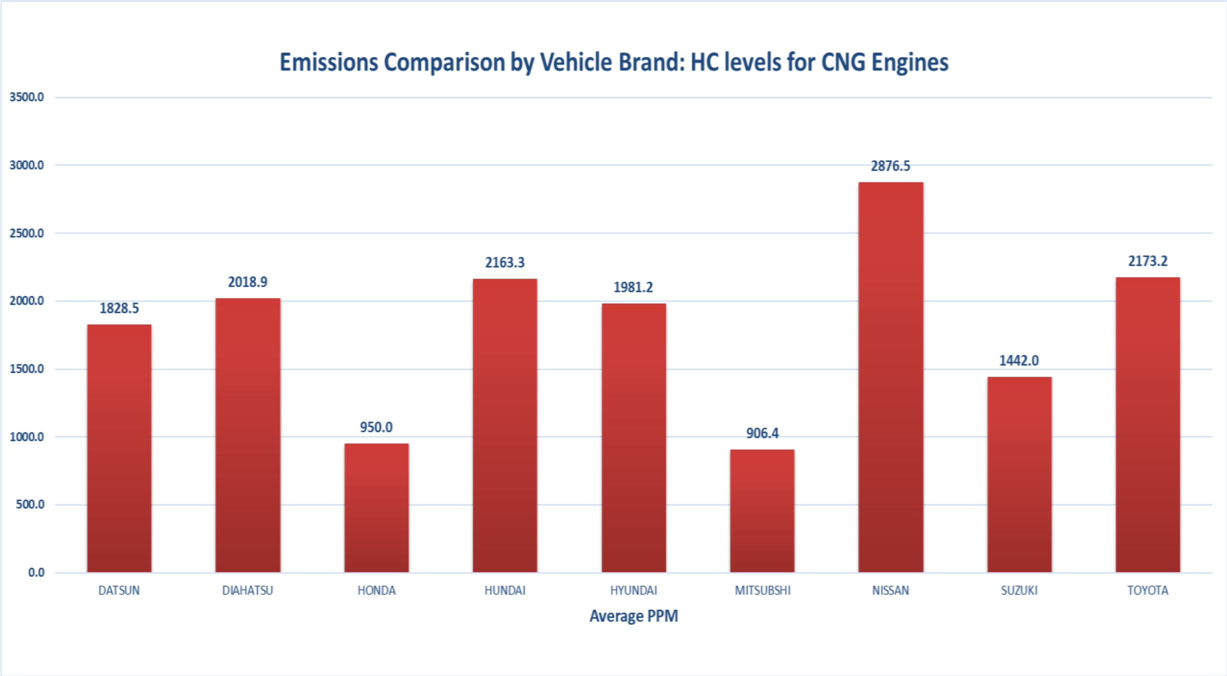


Figure 3.19 Emission Comparison by Vehicle Brand: Average HC Levels for CNG Engines

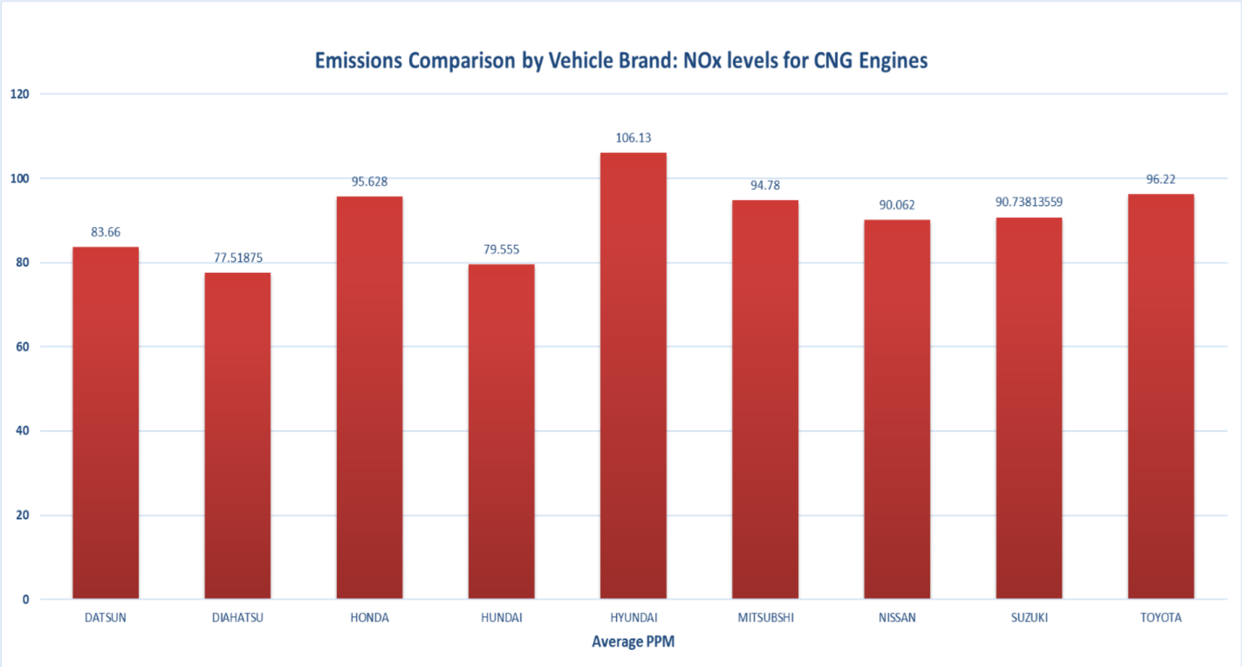
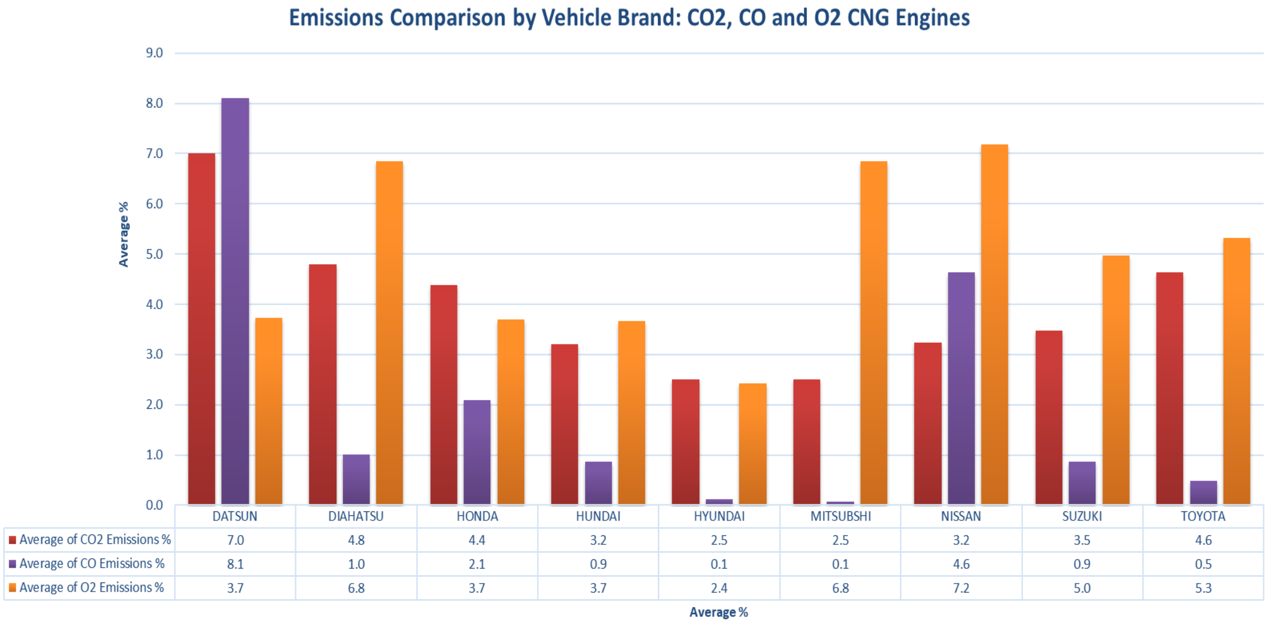


Figure 3.20 Emission Comparison by Vehicle Brand: Average NOx Levels for CNG Engines



	DATSUN	DIAHATSU	HONDA	HUNDAI	HYUNDAI	MITSUBSHI	NISSAN	SUZUKI	TOYOTA
🟥 Average of CO2 Emissions %	7.0	4.8	4.4	3.2	2.5	2.5	3.2	3.5	4.6
🟪 Average of CO Emissions %	8.1	1.0	2.1	0.9	0.1	0.1	4.6	0.9	0.5
🟧 Average of O2 Emissions %	3.7	6.8	3.7	3.7	2.4	6.8	7.2	5.0	5.3

Figure 3.21 Emission Comparison by Vehicle Brand: Average CO2, CO and O2 Levels for CNG Engines

Fig 3.21 shows emissions comparison of CO_2, CO and O2 emissions of CNG engines from different brand vehicles. CO_2 emissions appear to be close across all the brands on average; the highest emissions being 7% on average from Datsun vehicles while the lowest is from Hyundai and Mitsubishi 2% on average. CO emissions are strangely high from Datsun vehicles, the average being 8.1% while other brands mostly range under 2% except for Nissan vehicles which on average emit 4.6% CO. The O2 emission on average is close across all the brands, the highest emitter being Nissan at 7.2% closely followed by Mitsubishi at 6.8% while the lowest emitter is Hyundai at 2.4% on average. Across all the brands, Hyundai vehicles emit the least pollutants when it comes to CO, CO and O2, however; it emits higher amounts of NOx as can be seen in fig 3.19.

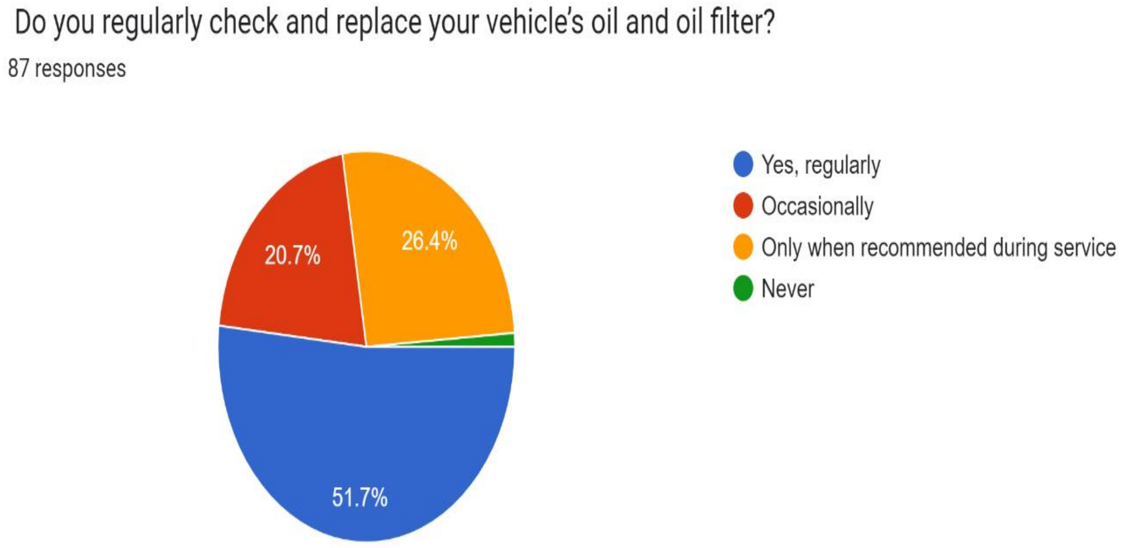
3.5 Vehicular Emission Survey Analysis

The online survey conducted in Islamabad underscored the significant relationship between vehicle maintenance practices and emissions levels. The findings indicate that while vehicle age and fuel type play a role in emissions, maintenance practices are critical determinants of air quality outcomes.

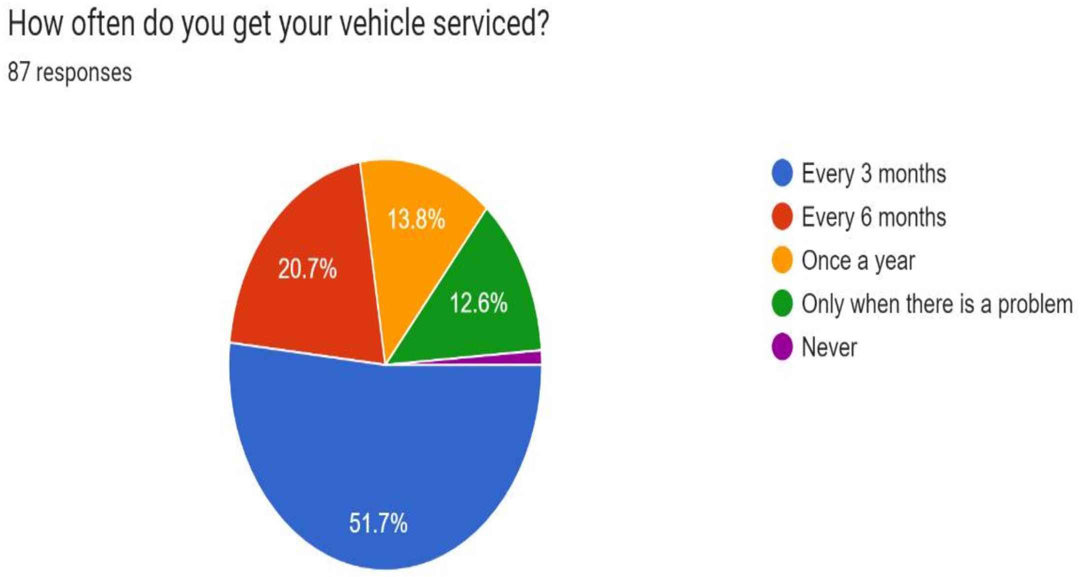
Table 4.1 Survey analysis summary

Maintenance issue	Percentage of respondents	Impact on emissions	Common consequences	Recommended frequency	Cost implications
Overdue Oil Changes	48.3%	High	Reduced engine efficiency, increased wear and tear	Every 3,000-5,000 miles	Increased fuel consumption, potential engine damage
Neglected Tire Rotations	30%	Moderate	Uneven tire wear, reduced fuel efficiency	Every 6,000-8,000 miles	Shortened tire lifespan, higher replacement costs
Ignored Brake Inspections	25%	High	Decreased braking performance, safety risks	Every 10,000-12,000 miles	Increased risk of accidents, costly repairs
Air Filter Replacement	20%	Moderate	Reduced air quality, decreased engine performance	Every 15,000-30,000 miles	Lower fuel efficiency, potential engine issues
Battery Maintenance	15%	Low	Starting issues, electrical problems	Every 3-5 years	Unexpected breakdowns, replacement costs
Coolant Flush	10%	Low	Overheating, engine damage	Every 30,000-50,000 miles	Engine overheating, costly repairs
Engine Tuning	35%	High	Poor engine performance, increased emissions	Every 10,000-20,000 miles	Reduced fuel efficiency, potential engine damage

Vehicle Maintenance Habits: Survey Response Breakdown


Do you regularly check and replace your vehicle’s oil and oil filter?

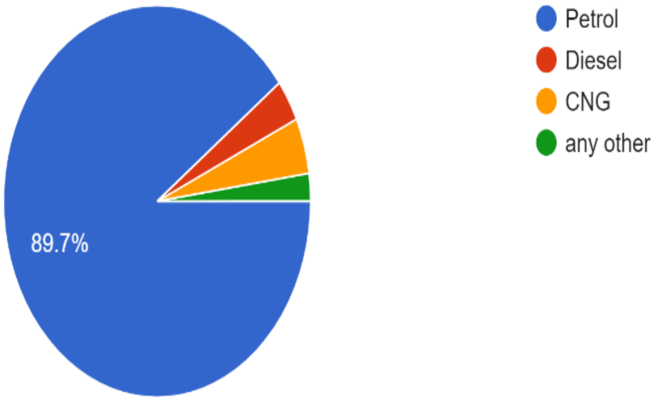
87 responses


How often do you get your vehicle serviced?

87 responses

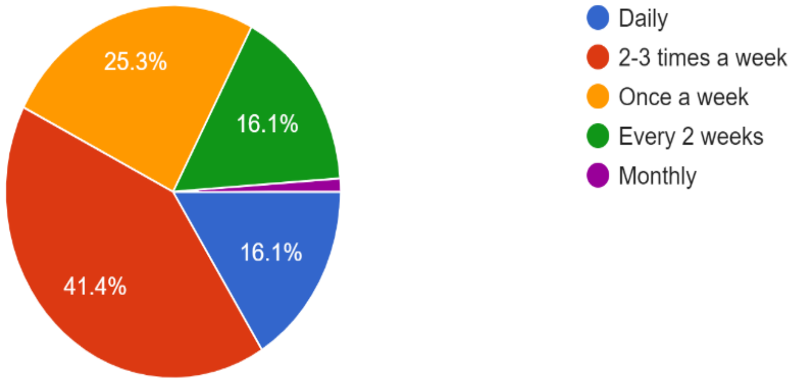
What type of fuel does your vehicle use?

87 responses



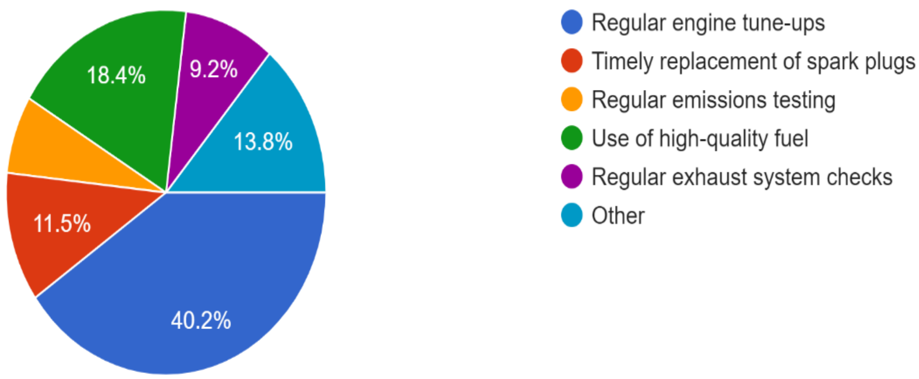
How often do you refuel or recharge your vehicle?

87 responses



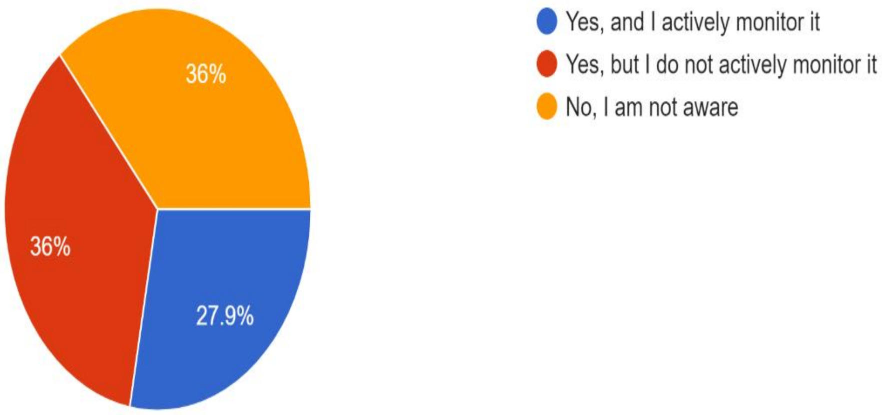
What preventive measures do you take to ensure your vehicle's emissions are within acceptable limits?

87 responses



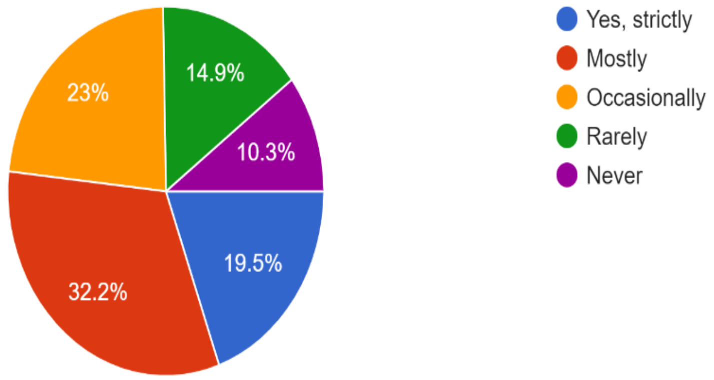
Are you aware of your vehicle’s emissions standards it adheres to?

86 responses



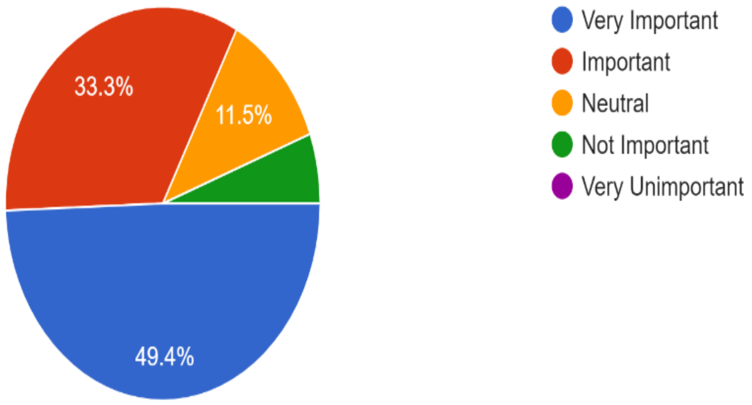
Do you follow the manufacturer’s maintenance schedule for your vehicle?

87 responses



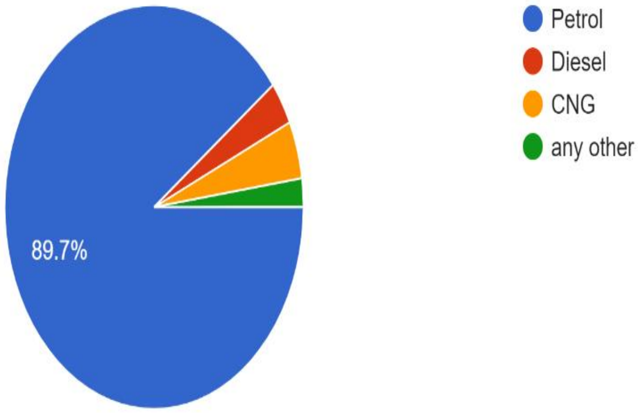
How important do you think regular vehicle maintenance is in reducing exhaust emissions?

87 responses



What type of fuel does your vehicle use?

87 responses



CONCLUSION

Diesel vehicles meet CO standards but exceed NOx limits, highlighting the need for better NOx reduction technologies like selective catalytic reduction (SCR) systems. Petrol vehicles exhibit variability in emissions, struggling with CO and occasional NOx spikes. Their combustion processes need refinement to ensure consistent compliance with Euro 2/3 standards. CNG vehicles, while performing well in terms of NOx and CO_2 emissions, show significant issues with CO and HC emissions, indicating a need for improved combustion efficiency and better emissions control mechanisms. In summary, while each vehicle type has strengths, CNG vehicles seem to have the most potential for environmental sustainability with further tuning of their CO and HC emissions. Diesel vehicles need NOx control, and Petrol vehicles require more consistency in emissions management across the board.

Based on a survey, it appears that a lack of engine maintenance likely plays a significant role in the increase of these values, further exacerbating emissions issues across different fuel types. The survey responses on vehicle maintenance habits reveal a significant trend of neglect among vehicle owners. This lack of regular maintenance is a major contributor to increased emissions, which negatively impacts the environment. The most common maintenance issues identified include overdue oil changes, neglected tire rotations, and ignored brake inspections. These issues not only lead to higher emissions but also result in reduced vehicle efficiency, increased wear and tears, and potential safety risks.

Addressing these maintenance issues through regular and timely vehicle upkeep can significantly reduce emissions and improve overall vehicle performance. It is crucial for vehicle owners to adhere to recommended maintenance schedules to ensure their vehicles operate efficiently and sustainably. By doing so, they can contribute to a cleaner environment and enhance the longevity and safety of their vehicles.

RECOMMENDATIONS

With the help of the research, we can present the following vital suggestions for decreasing exhaust emissions from vehicles:

a) Improve fuel quality standards and enforcement mechanisms at refinery levels and among oil marketing companies.

b) Emissions from in use vehicles can be controlled by retrofitting.

c) Hydrogen and electric powered vehicles (in the form of batteries and fuel cells) can be replaced by vehicles using conventional combustion engines in big cities.

d) One of the strategies is to relocate uncontrolled or excessively polluting vehicles to other less populated areas with respect to vehicles and the traffic flow.

e) Implementation of '**NO Drive Days** based on transportation control measures and to reduce traffic density.

f) Tax or other incentives for people using Environmentally friendly vehicles

g) Enforce vehicular emission standards to restrict pollutants ensuring regular inspections and strict penalties for non-compliance.

h) The petrol station should carry out regular checks on fuel quality and prevent adulteration.

i) Encourage the use of environmentally friendly fuels and promote clean fuel programs.

j) Encourage the use of environmentally friendly fuels and promote clean fuel programs.

k) Setting up an independent testing organization to regularly inspect vehicles for emissions at designated sites all over the country..

l) Review and update the National Environmental Quality Standards (NEQS) for motor vehicle exhaust emissions.

m) Legislation (required from National and Provincial Assemblies) must be passed to set and monitor exhaust emission levels in all vehicles.

n) Create more environmental courts that oversight the diesel and gasoline quality.

o) Need to expand citywide Vehicle Emission Testing System (VETS) facilities centers in the whole country.

p) Upgradation of public transportation networks, transport management and improving road conditions of traffic

q) Implementing a Vehicle Emission Testing System in Islamabad (as a pilot project), with plans for expansion to other urban areas.

r) Provide training to traffic cops to effectively identify and address vehicles emitting excessive smoke and noise.

s) Create a monitoring program under the EPA's direction to systematically test and keep an eye on vehicle emissions.

t) Establish a thorough surveillance mechanism to track and report on emissions from moving vehicles, and make sure that faulty cars are strictly enforced until they are certified and fixed.

u) Make it mandatory for commercial vehicles to undergo routine inspections by traffic police and vehicle examiners, and for public service vehicles to receive periodic condition certificates.

v) Prohibit the sale of vehicle auto parts, which have the potential to negatively impact engine performance and raise emissions.

w) Ban the sale of substandard or recycled engine oils, as these products pose a risk to engines and pollute the environment.

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ANNEXURE- I

Field Visit


K.S.R

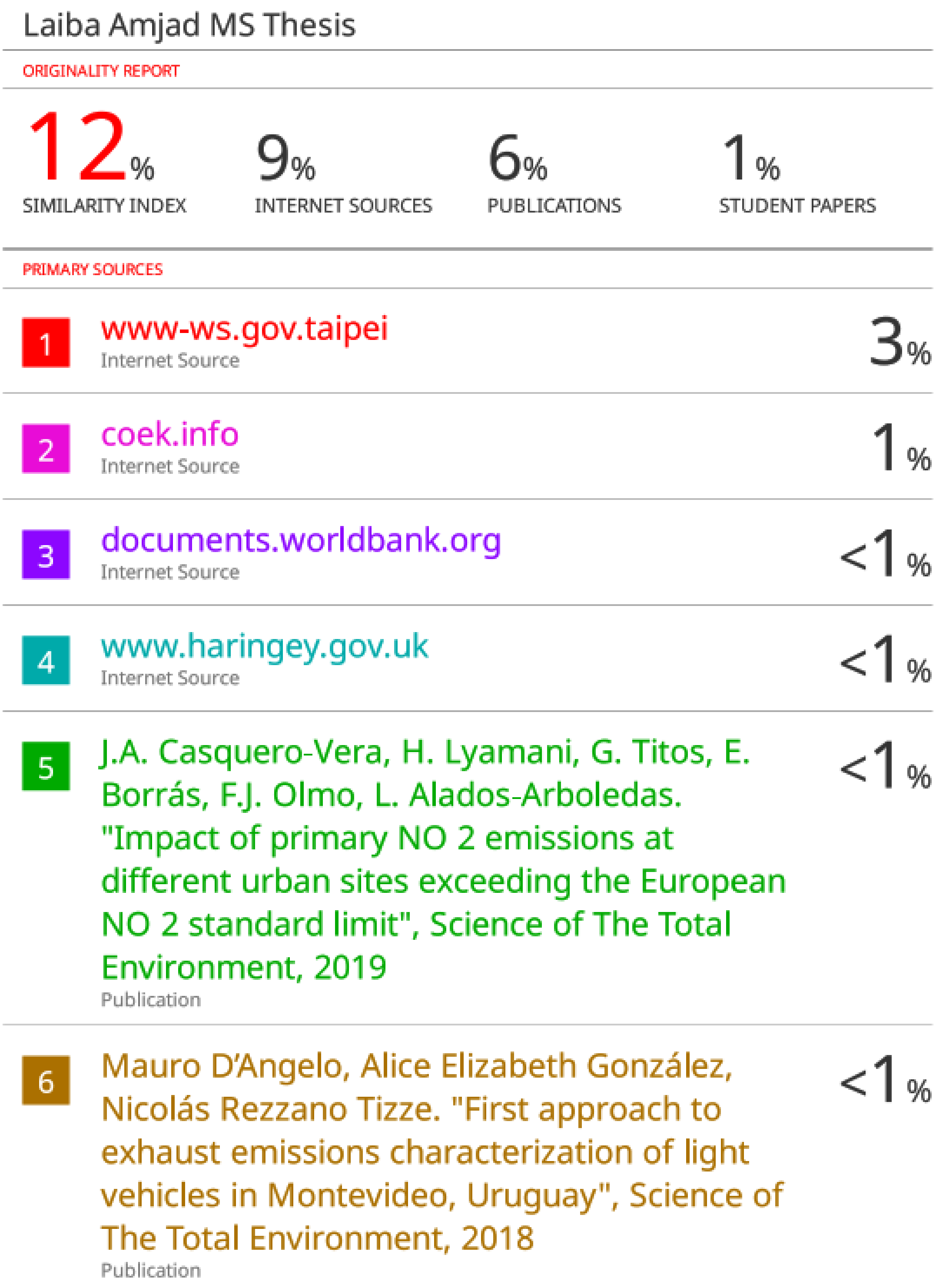

KSR
STEEL
Karachi Steel

Annexure – II - Supporting Data

VEHICLE	Model	Engine Size (CC)	Milage (KM)	Fuel Type	Sector	CO2 Emissions %	CO Emissions %	NOx Emissions PPM	HC Emissions PPM	O2 Emissions %
DAIHATSU	Mira2007	660	93,475	Petrol	I-10	3.63	1.08	229	145	0.9
DAIHATSU	Mira2017	660	111,660	Petrol	I-10	4.6	9.77	121.5	9.89	2.11
DAIHATSU	TERIOS-2012	1500	13,548	Petrol	I-10	10.95	2.2	151	224	1.61
DAIHATSU	Move-2021	660	8,952	Petrol	I-10	6.9	0.1	117	95.7	22.12
DAIHATSU	Mira-2012	660	108,200	Petrol	I-10	13.86	0.19	101	205	1.01
DAIHATSU	Charade-1983	1000	82,500	Petrol	I-10	6.97	6.06	106	201	0.61
HONDA	CITY 2020	1300	77,000	Petrol	I-10	9.52	1.95	109	118	0.62
HONDA	City 2007	1300	238,200	Petrol	I-10	10.92	2.45	120	115	0.69
HONDA	CITY 2009 Aspire 1.5	1500	140,000	Petrol	I-10	1.64	1.75	98	105	0.55
HONDA	CITY 2009	1300	70,500	Petrol	I-10	10.06	1.95	109	118	0.62
HONDA	Civic-2003	1600	230,000	Petrol	I-10	8.88	1.05	117	572	0.41
HONDA	Civic-2007	1800	267,200	Petrol	I-10	2.5	1.51	115	552	0.55
HONDA	City-2008 Aspire 1.5	1500	175,500	Petrol	I-10	2	2.01	95	126	0.61
HONDA	City-2019	1300	105,000	Petrol	I-10	11.1	10.8	90.2	102.96	0.15
HONDA	City-2005	1300	129,000	Petrol	I-10	10.54	8.81	140.8	903.1	3.74
HONDA	City-2003	1300	234,800	Petrol	I-10	9.52	6.84	206.8	245.3	0.09
HONDA	Accord-2006	2400	105,600	Petrol	I-10	10.63	0.19	78.65	12.98	0.19
HONDA	Accord-2003	2000	77,900	Petrol	I-10	12.46	6.62	77.28	206.8	3.29
HONDA	Civic-1996	1600	207,000	Petrol	I-10	8.68	6.79	190.3	10.13	2.94
HONDA	Civic-2016	1800	21,850	Petrol	I-10	0.9	1.81	180.5	186	0.37
HONDA	Civic-2019	1800	26,890	Petrol	I-10	0.66	0.01	82.35	6.49	22.45
HONDA	BR-V 2018	1800	2,715	Petrol	I-10	2.1	0.06	95.63	12.1	19.11
HONDA	City-2019	1300	9,454	Petrol	I-10	7.5	0.07	101.7	72.2	0.12
HONDA	City-2009	1300	130,000	Petrol	I-10	5.2	4.59	76.45	281.7	0.08
HONDA	Accord-2005	2400	107,000	Petrol	I-10	7.6	0.32	101.59	89.87	0.14
HONDA	Accord-2003	2000	91,500	Petrol	I-10	11.46	6.84	189.45	278	0.21
HONDA	Civic-1996	1600	213,000	Petrol	I-10	9.45	6.8	189.45	17.2	2.67
HONDA	Civic-2019	1800	45,000	Petrol	I-10	1.2	0.01	150.15	4.5	18.37
HONDA	Civic-2023	1800	27,500	Petrol	I-10	0.85	0.06	107.77	12.1	19.11
KIA	SPORTAGE 2020	2000	46,250	Petrol	I-10	6.21	0.74	125	16	22.05
KIA	STONIC 2021	1400	55,100	Petrol	I-10	0.26	0.54	97	13	14.2
KIA	SPORTAGE- 2002	2000	306,400	Petrol	I-10	8.31	1.85	162.41	388.8	0.64
MAZDA	DEMIO-2006	1300	107,000	Petrol	I-10	8.18	1.5	82.95	330.3	0.47
MITSUBISHI	MIRAGE- 2015	1000	20,267	Petrol	I-10	12.78	0.19	71.85	84.42	8.67
NISSAN	SUNNY 1978	1200	166,000	Petrol	I-10	11.36	2.65	92.4	1022.1	11.07
NISSAN	SUNNY	1600	1,265,000	Petrol	I-10	8.56	2.64	108.33	938	1.29
SUZUKI	VAGON-R2015	1000	32,540	Petrol	I-10	10.57	0.37	105.95	124.2	1.64
SUZUKI	WAGON-R 2016	1000	34,900	Petrol	I-10	6.84	0.82	129.98	142	1.11
SUZUKI	FX 1983	800	113,000	Petrol	I-10	9.23	7.33	108.76	499	0.53
SUZUKI	Swift 2008	1300	91,800	Petrol	I-10	10.45	2.18	131	199	1.28
SUZUKI	Wagon-R 2019	1000	77,000	Petrol	I-10	15.48	8.62	144	351	1.36
SUZUKI	SURF-2018	1300	13,440	Petrol	I-10	11.85	0.06	199.7	17.1	1.24
SUZUKI	CULTUS VXL 2019	1000	3,960	Petrol	I-10	12.27	0.01	119.1	13.2	1.21
SUZUKI	SWIFT- 2010	1300	70,500	Petrol	I-10	10.8	0.32	137.75	110	1.3
SUZUKI	EVERY 2013	660	28,600	Petrol	I-10	10.84	0.1	91.12	31.79	5.29
SUZUKI	SWIFT-2015	1300	21,500	Petrol	I-10	11.88	0.08	160	89.55	17.98
SUZUKI	BALENO- 2000	1300	284,000	Petrol	I-10	12.35	5.56	141.3	387	0.32
SUZUKI	Mehran- 2015	800	34,800	Petrol	I-10	8.5	0.14	113.45	266	8.65
SUZUKI	Mehran- 2008	800	118,000	Petrol	I-10	11.24	1.94	260.2	382.5	1.08
SUZUKI	Mehran- 2001	800	190,000	Petrol	I-10	7.62	2.08	84.55	274.08	0.47
SUZUKI	Mehran- 2016	800	34,000	Petrol	I-10	10.48	0.27	205.93	27.27	16.35
SUZUKI	KHYBER- 1998	1000	114,000	Petrol	I-10	9.28	1.16	204.46	200.45	0.37
SUZUKI	MARGALLA- 1994	1300	105,000	Petrol	I-10	9.88	8.74	108.68	685.65	0.31
SUZUKI	FX-1987	800	215,000	Petrol	I-10	8.17	4.06	158.39	926.1	0.49
SUZUKI	SWIFT-2018	1300	11,800	Petrol	I-10	5.25	0.06	126.18	103.65	1.2
SUZUKI	BALENO-2000	1300	275,000	Petrol	I-10	10.27	1.26	233.1	226.85	0.88
SUZUKI	BALENO-2005	1300	222,000	Petrol	I-10	10.78	8.65	157.3	337.2	1.64
SUZUKI	Mehran-2018	800	43,000	Petrol	I-10	11.6	0.39	101.9	399.95	3.35
SUZUKI	Mehran-2015	800	32,000	Petrol	I-10	10.27	0.1	70.3	271.75	2.93
SUZUKI	Mehran-2013	800	59,500	Petrol	I-10	10.08	1.94	80.4	2435.55	16.35
SUZUKI	Mehran-2008	800	118,000	Petrol	I-10	6.35	0.09	135.68	188.1	2.87
SUZUKI	Mehran-2004	800	186,500	Petrol	I-10	10.39	1.97	143.28	378	2.66
SUZUKI	Mehran-2001	800	192,000	Petrol	I-10	12.38	1.87	83.45	389.5	0.41
SUZUKI	Mehran-2017	800	30,150	Petrol	I-10	4.5	6.83	98.19	493.05	2.68
SUZUKI	KHYBER-1998	1000	113,000	Petrol	I-10	10.31	0.5	128.15	95.95	0.2
SUZUKI	CULTUS-1998	1000	82,600	Petrol	I-10	7.18	2.55	68.92	915.35	1.03
SUZUKI	Mehran-1987	800	115,800	Petrol	I-10	10.09	1.6	107.62	278.35	0.5
SUZUKI	MARGALLA- 1994	1300	72,500	Petrol	I-10	6.86	3.13	77.9	703	1.42
SUZUKI	FX-1987	800	289,000	Petrol	I-10	8.85	2.7	130.2	934.1	0.45
SUZUKI	Wagon-R 2019	1000	114,256	Petrol	I-10	0.9	0.02	122.8	8.29	0.08
SUZUKI	Wagon-R 2015	1000	22,200	Petrol	I-10	9.48	0.75	136.55	26.6	0.31
SUZUKI	Wagon-R 2018	1000	24,000	Petrol	I-10	0.65	0.13	228	8.45	0.47
SUZUKI	Wagon-R 2015	1000	54,500	Petrol	I-10	1.25	1.05	56.7	129.4	0.68
SUZUKI	Wagon-R 2015	1000	22,200	Petrol	I-10	1.2	0.76	147.25	29.4	0.3
SUZUKI	Wagon-R 2018	1000	26,400	Petrol	I-10	0.75	0.1	93.6	9.55	0.42
SUZUKI	SWIFT-2015	1300	49,500	Petrol	I-10	2.8	0.14	110.2	178	11.18
SUZUKI	BOLAN-1991	800	115,000	Petrol	I-10	10.63	0.28	101.25	178.6	2.08
SUZUKI	Alto 2014	660	201,600	Petrol	I-10	5.85	0.16	94.5	121.75	1.18
SUZUKI	CULTUS-2018	1000	64,200	Petrol	I-10	12.3	2.83	146.79	331.05	0.3
SUZUKI	Mehran-2010	800	129,600	Petrol	I-10	8.06	1.04	100.99	1151.1	0.96
SUZUKI	CULTUS VXL 2016	1000	62,000	Petrol	I-10	9.75	0.17	174.37	82.65	1.03
TOYOTA	FIELDER 2007	1500	189,000	Petrol	I-10	4.37	2.51	125	1298	0.9
TOYOTA	Alto 2020	660	95,000	Petrol	I-10	10.62	0.42	102.6	655.5	1.19
TOYOTA	PASSO-2017	1000	26,700	Petrol	I-10	10.15	0.09	90.75	117.29	21.89
TOYOTA	Vitz2016	1000	3,800	Petrol	I-10	12.36	1.14	118.65	196.3	6.44
TOYOTA	Corolla- 2015	1500	91,000	Petrol	I-10	12.65	1.13	112.58	305.55	5.8
TOYOTA	Corolla 2020 GLI	1300	240,000	Petrol	I-10	10.91	0.11	114.45	84.07	0.09
TOYOTA	Corolla- 2022	1300	111,600	Petrol	I-10	11.3	5.8	131.43	527.95	0.19
TOYOTA	VITZ 2018	1000	5,400	Petrol	I-10	8.6	0.02	133	8.58	0.07
TOYOTA	Corolla-2008	1300	65,500	Petrol	I-10	6.74	6.45	76	389.05	1.24
TOYOTA	Vitz2014	1000	72,500	Petrol	I-10	6.4	0.1	85.5	11.4	0.05
TOYOTA	Vitz2007	1000	159,000	Petrol	I-10	12.5	0.19	104.5	92.9	2.1
TOYOTA	FIELDER 2006	1500	69,700	Petrol	I-10	5.88	0.05	93.1	27.3	5.16
TOYOTA	Corolla-2001	1300	148,000	Petrol	I-10	9.75	8.46	146.85	50.35	4.86
TOYOTA	Corolla-2019	1300	8,400	Petrol	I-10	5.93	0.03	135.45	10	0.1
TOYOTA	Corolla-2006	1300	104,000	Petrol	I-10	9.64	6.26	224.72	614.9	6.13
TOYOTA	Vitz2017	1000	73,600	Petrol	I-10	6.84	0.1	109.73	12.1	0.06
TOYOTA	Vitz2008	1000	159,500	Petrol	I-10	10.39	0.24	119.15	139	2.62
TOYOTA	Corolla Altis 2015	1600	69,700	Petrol	I-10	2.1	0.05	184.16	24.7	16.26
TOYOTA	Corolla Altis 2019	1800	45,700	Petrol	I-10	1.1	0.06	165	6.1	19.68

VEHICLE	Model	Engine Size (CC)	Milage (KM)	Fuel Type	Sector	CO2 Emissions %	CO Emissions %	NOx Emissions PPM	HC Emissions PPM	O2 Emissions %
DIAHATSU CHARADA	2009	1000	102,000	CNG	I-10	5	0.15	66.45	618.54	18.68
DAIHATSU CHARADA	1984	1000	336,000	CNG	I-10	6	4.89	99.97	2862.66	0.44
DATSUN-T	1980	1300	78,000	CNG	I-9	7	8.1	83.66	1828.45	3.73
DIAHATSU CHARADA	1987	1000	71,880	CNG	I-9	6	0.08	96.93	2396.16	11.26
DIAHATSU CHARADA	1985	1000	77,000	CNG	I-9	4.7	2.26	54.44	2227	1.24
DIAHATSU CHARADA	1988	1500	118,000	CNG	I-9	4.7	0.06	19.15	2415.54	9.92
DIAHATSU CHARADA	1986	1000	138,000	CNG	I-9	4.6	0.1	82.43	4330.35	7.06
DIAHATSU COURE	2007	800	120,000	CNG	I-10	4.2	0.45	86	633.27	3.01
DIAHATSU COURE	2009	1000	20,700	CNG	I-10	3.2	0.08	114.78	667.35	3.14
HONDA CITY	2006	1300	90,750	CNG	I-10	3.2	0.07	83.34	774.14	3.26
HONDA CITY	2003	1300	143,000	CNG	I-10	4.6	8.18	126.93	925.75	6.16
HONDA CIVIC	2002	1600	149,000	CNG	I-10	4.7	2.09	64.04	200.1	0.61
HONDA CIVIC	2003	1600	134,000	CNG	I-10	4.7	0.08	115.58	645.43	6.06
HONDA CIVIC	2001	1600	186,000	CNG	I-10	4.7	0.01	88.25	2204.45	2.38
HUNDAI SANTRO	2004	1000	85,000	CNG	I-10	4.1	0.1	85.47	1921.81	3.15
HUNDAI-T	2002	1300	88,000	CNG	I-9	2.3	1.62	73.64	2404.82	4.18
HYUNDAI CENTRO	2004	1000	19,800	CNG	I-10	2.5	0.14	98.88	2569.52	3.52
HYUNDAI SANTRO	2007	1000	89,000	CNG	I-10	2.5	0.09	113.38	1392.84	1.33
MITSUBSHI LANCER	2006	1300	45,000	CNG	I-10	2.5	0.07	94.78	906.43	6.84
NISSAN	1979	1300	115,000	CNG	I-9	3.1	8.64	78.68	2980.96	12.2
NISSAN SUNNY	1989	1000	96,000	CNG	I-10	3.3	0.35	75.32	2708.76	2.04
NISSAN SUNNY	1974	1300	141,000	CNG	I-9	3.6	0.35	103.59	3445.38	1.2
NISSAN SUNNY GL	1972	1200	149,000	CNG	I-9	3.5	2.38	78.99	1558.58	12.84
NISSAN SUNNY GL	1978	1200	118,000	CNG	I-9	2.7	11.46	113.73	3688.61	7.62
SUZUKI ALTO	2006	1000	108,000	CNG	I-10	2.9	0.13	58.91	1130.25	2.58
SUZUKI ALTO	2009	1000	108,000	CNG	I-10	3.5	0.13	101.21	769.75	2.72
SUZUKI ALTO	2011	1000	45,000	CNG	I-10	3.8	0.07	96.79	707.4	6.78
SUZUKI ALTO	2006	1000	71,500	CNG	I-10	2.6	0.97	114.87	557.75	0.6
SUZUKI ALTO	2004	800	115,000	CNG	I-10	2.9	0.12	36.84	1156.5	2.77
SUZUKI ALTO	2007	1000	32,500	CNG	I-10	3.4	2.51	118.18	389.85	9.64
SUZUKI ALTO	2007	1000	34,400	CNG	I-10	3.1	2.31	108.68	511.75	9.94
SUZUKI ALTO	2007	1000	54,500	CNG	I-9	3.5	0.12	89.28	457.55	6.15
SUZUKI ALTO	2018	660	31,200	CNG	I-9	2.6	0.3	108.48	306.23	7.88
SUZUKI ALTO	2008	1000	96,000	CNG	I-9	2.3	0.24	100.6	398.4	1.87
SUZUKI ALTO	2005	1000	100,000	CNG	I-9	2.8	0.35	81.19	1397.96	1.92
SUZUKI ALTO	2006	1000	98,400	CNG	I-9	3.2	0.16	70.76	1480.25	10.66
SUZUKI BOLAN	1995	800	48,800	CNG	I-9	3.5	0.25	97.79	2074.2	3.77
SUZUKI BOLAN	1989	800	115,000	CNG	I-9	3.8	2.55	84.58	3979	11.12
SUZUKI BOLAN	1998	800	87,000	CNG	I-9	3.4	0.5	46.39	1023.5	6.98
SUZUKI BOLAN	1993	800	59,200	CNG	I-9	3.1	0.16	91.91	2412.8	4.6
SUZUKI CULTUS	2010	1000	27,500	CNG	I-10	3.7	0.8	78.53	625.95	1.51
SUZUKI CULTUS	2007	1000	71,000	CNG	I-10	3.8	1.47	90.75	665.5	2.38
SUZUKI CULTUS	2008	1000	86,000	CNG	I-10	3.5	0.07	109.2	1385.1	2.07
SUZUKI CULTUS	2004	1000	72,600	CNG	I-10	3.1	0.14	73.23	1605.4	2.64
SUZUKI CULTUS	2012	1000	60,000	CNG	I-10	2.9	0.16	94.11	1085.85	3.45
SUZUKI CULTUS	1996	1000	79,500	CNG	I-10	3.4	0.18	98.21	2594.85	3.66
SUZUKI CULTUS	2009	1000	57,600	CNG	I-10	3.3	0.58	97.86	1020.9	0.93
SUZUKI HIROOF BOLAN	2006	880	102,500	CNG	I-10	3.4	0.03	109.71	3071.6	7.78
SUZUKI HIROOF BOLAN	2010	800	37,200	CNG	I-10	3.6	0.19	42.35	2148	2.89
SUZUKI HIROOF BOLAN	2002	800	84,000	CNG	I-10	2.7	6.7	97.2	2535.8	6.78
SUZUKI HIROOF BOLAN	2001	800	52,500	CNG	I-10	2.8	0.09	104.48	1143.85	3.28
SUZUKI HIROOF BOLAN	2005	800	46,900	CNG	I-10	3.7	0.13	120.08	1387.8	6.16
SUZUKI HIROOR	1988	800	57,800	CNG	I-10	3.2	0.09	90.25	2058.9	6.35
SUZUKI HIROOR	2001	800	79,000	CNG	I-10	3.6	0.12	25.11	1900.75	7.34
SUZUKI KHYBER	2009	1000	60,500	CNG	I-10	3.8	0.09	119.55	469	2.52
SUZUKI KHYBER	1992	1000	120,000	CNG	I-10	3.6	0.16	85.68	1725	3.41
SUZUKI KHYBER	1997	1000	102,500	CNG	I-9	3.3	0.14	79.3	2944.4	1.13
SUZUKI KHYBER	1995	1000	92,500	CNG	I-9	3.7	0.72	47.67	1988.3	1.49
SUZUKI KHYBER	1990	1000	114,000	CNG	I-9	3.2	0.17	80.55	1254	3.48
SUZUKI KHYBER	1994	1000	115,000	CNG	I-9	3.4	0.08	101.85	2625.3	2.9
SUZUKI KHYBER	1992	1000	115,000	CNG	I-9	4.2	2.19	87.23	2654	9.24
SUZUKI LIANA	2006	1300	126,000	CNG	I-10	3.4	0.1	105.68	720	3.16
SUZUKI LIANA	2007	1300	28,500	CNG	I-10	3.6	0.1	142.32	523.5	1.51
SUZUKI MEHRAN	2002	800	71,000	CNG	I-10	4.7	0.25	105.37	1750	1.74
SUZUKI MEHRAN	2005	800	24,500	CNG	I-10	3.5	0.27	61.91	1014	2.52
SUZUKI MEHRAN	2018	800	6,000	CNG	I-10	5.3	0.02	77.59	304	7.86
SUZUKI MEHRAN	2011	800	102,000	CNG	I-10	3.5	0.14	105.76	1315	3.51
SUZUKI MEHRAN	2002	800	133,000	CNG	I-10	3.4	0.08	39.25	3536	3.96
SUZUKI MEHRAN	2001	800	132,000	CNG	I-10	3.2	3.39	89.45	1328	9.81
SUZUKI MEHRAN	1992	800	119,760	CNG	I-10	3.1	2.28	100.67	2313	2.43
SUZUKI MEHRAN	2003	800	132,000	CNG	I-10	3.8	1.16	114.05	812	7.64
SUZUKI MEHRAN	2009	800	109,000	CNG	I-10	3.4	0.11	106.72	615	5.87
SUZUKI MEHRAN	2001	800	118,500	CNG	I-10	3.9	0.08	95.86	2536	4.02
SUZUKI MEHRAN	2006	800	105,000	CNG	I-10	3.2	0.07	124.69	620	6.91
SUZUKI MEHRAN	2005	800	166,800	CNG	I-10	3.2	0.17	141.84	1658	6.73
SUZUKI PICKUP BOLAN	1985	800	154,800	CNG	I-9	3.9	9.85	92.7	1806	8.8
SUZUKI PICKUP BOLAN	1984	800	162,000	CNG	I-9	3.3	0.23	45.72	1225	6.16
SUZUKI PICKUP BOLAN	1989	800	116,760	CNG	I-9	3.2	0.19	93.89	745	11.9
SUZUKI PICKUP BOLAN	1984	800	92,000	CNG	I-9	5.2	4.47	102.38	1320	1.53
SUZUKI PICKUP RAVI	2011	800	20,500	CNG	I-9	3.7	0.09	79.43	1110	7.08
SUZUKI PICKUP RAVI	2006	800	75,600	CNG	I-9	3.4	0.14	105.6	1293	3.57
SUZUKI PICKUP RAVI	1987	800	134,400	CNG	I-9	4.1	2.68	69.03	686	12.7
SUZUKI-C- BOLAN	2003	600	78,700	CNG	I-9	4.9	0.31	114.28	2208	2.61
TOYOTA COROLLA	1996	1300	26,300	CNG	I-10	4.9	0.17	33.69	3890	3.43
TOYOTA COROLLA	2001	1300	49,900	CNG	I-10	4.2	0.21	89.68	3035	2.72
TOYOTA COROLLA	1993	1300	248,200	CNG	I-10	4.4	2.16	117.31	6764	0.63
TOYOTA COROLLA	2007	1300	240,000	CNG	I-10	5.5	0.06	102.8	1735	2.65
TOYOTA COROLLA	2002	1300	234,800	CNG	I-10	4.5	0.1	89.58	1246	2.53
TOYOTA COROLLA	2004	1300	114,480	CNG	I-10	4.8	0.11	117.61	3318	3.23
TOYOTA COROLLA	2004	1300	92,500	CNG	I-10	4.8	0.15	101.58	1171	9.25
TOYOTA COROLLA	1998	1300	144,700	CNG	I-10	3.8	0.14	108.51	2084	7.61
TOYOTA HIACE	1994	3000	159,600	CNG	I-10	5.2	0.29	85.56	4061	2.21
TOYOTA HIACE	1990	3500	176,640	CNG	I-10	3.9	0.22	119.87	2646	10.16
TOYOTA HIACE	2007	2000	115,000	CNG	I-10	5.1	0.07	114.34	632	3.64
TOYOTA HIACE	1992	1300	193,960	CNG	I-9	4.9	1.14	107.53	860	11.82
TOYOTA HIACE	1988	1300	145,000	CNG	I-9	4.1	1.63	88.76	1030	2.85
TOYOTA PIRADO	1990	3378	255,000	CNG	I-10	4.9	1.64	88.76	590	11.21
TOYOTA VITZ	2001	1000	140,400	CNG	I-10	4.6	0.03	115.92	2582	2.9
TOYOTA VITZ	2005	1000	108,000	CNG	I-10	4.4	0.14	66.93	764	11.21
TOYOTA VITZ	2009	1000	105,000	CNG	I-10	4.9	0.08	87.31	537	2.42

VEHICLE	MODEL	Manufacturers	Engine Size	Fuel Type	Sector	CO2 Emissions %	CO Emissions %	NOx Emissions PPM	HC Emissions PPM	Smoke	O2 Emissions %
TRUCK TRAILER		NISSAN		DIESEL		12.55	0.9	263	0	1	0.53
TRUCK TRAILER		NISSAN		DIESEL		5.92	0.7	266	0	1	0.71
TRUCK TRAILER		NISSAN		DIESEL		11.61	0.85	269	0	1	0.44
TRUCK TRAILER		HINO		DIESEL		7.2	0.92	258	0	1	0.23
TRUCK TRAILER		HINO		DIESEL		12.8	0.83	281	0	1	0.62
TRUCK TRAILER		ISUZU		DIESEL		12.89	0.83	281	0	1	0.65
TRUCK TRAILER		UD COASTER		DIESEL		11.91	0.83	281	0	1	0.56
TRUCK TRAILER		DONGFONG		DIESEL		12.5	0.83	281	0	1	0.33
TRUCK TRAILER		NISSAN DIESEL		DIESEL		10.55	0.91	281	0	1	0.79
TRUCK TRAILER		NISSAN DIESEL		DIESEL		11.91	0.91	281	0	1	0.71
TRUCK TRAILER		HINO		DIESEL		12.45	0.84	281	0	2	0.67
TRUCK TRAILER		NISSAN		DIESEL		12.22	0.83	281	0	1	0.52
TRUCK TRAILER		NISSAN		DIESEL		11.5	0.83	281	0	1	0.63
TRUCK TRAILER		NISSAN		DIESEL		14.85	0.83	281	0	1	0.48
PRIME MOVER		FAW		DIESEL		6.07	0.93	285	0	2	0.56
OIL TANKER TRAILER		DONG FENG		DIESEL		17.81	0.75	283	0	1	0.72
OIL TANKER		FAW		DIESEL		16.71	0.66	278	0	1	0.24
OIL TANKER		FAW		DIESEL		12.33	0.66	278	0	1	0.34
OIL TANKER		FAW		DIESEL		6.11	0.66	278	0	1	0.59
OIL TANKER		ISUZU		DIESEL		15.02	0.72	296	0	1	0.77
OIL TANKER		ISUZU		DIESEL		7.21	0.78	292	0	1	0.41
OIL TANKER		ISUZU		DIESEL		11.6	0.81	304	0	1	0.26
OIL TANKER		FAW		DIESEL		15.29	0.65	335	0	1	0.68
OIL TANKER		FAW		DIESEL		14.58	0.79	265	0	1	0.48
OIL TANKER TRAILER		FOTON		DIESEL		17.81	0.83	278	0	1	0.57
OIL TANKER TRAILER		FOTON		DIESEL		20.03	0.84	307	0	1	0.69
OIL TANKER TRAILER		FOTON		DIESEL		8.12	0.89	285	0	1	0.25
OIL TANKER TRAILER		FOTON		DIESEL		5.1	0.62	284	0	1	0.71
OIL TANKER		FAW		DIESEL		8.25	0.79	272	0	1	0.45
OIL TANKER		FAW		DIESEL		6.11	0.86	285	0	1	0.77
OIL TANKER		FAW		DIESEL		7.2	0.96	297	0	1	0.73
OIL TANKER		FAW		DIESEL		8.1	0.83	318	0	1	0.61
OIL TANKER		FAW		DIESEL		10.89	0.99	328	0	1	0.34
OIL TANKER		FAW		DIESEL		9.14	0.85	306	0	1	0.72
OIL TANKER		FAW		DIESEL		5.55	0.73	313	0	1	0.49
OIL TANKER		FAW		DIESEL		16.69	0.87	295	0	1	0.54
OIL TANKER		FAW		DIESEL		13.39	0.95	306	0	1	0.62
OIL TANKER		FAW		DIESEL		13.29	0.83	281	0	1	0.71
OIL TANKER TRAILER		DONG FENG		DIESEL		9.53	0.77	297	0	1	0.68
OIL TANKER		FAW		DIESEL		14.52	0.86	283	0	1	0.29
OIL TANKER		NISSAN		DIESEL		7.82	0.73	266	0	1	0.65
OIL TANKER TRAILER		FOTON		DIESEL		13.1	0.89	285	0	1	0.45
OIL TANKER		FAW		DIESEL		10.08	0.65	335	0	1	0.28
OIL TANKER TRAILER		NISSAN		DIESEL		11.18	0.74	283	0	1	0.77
OIL TANKER TRAILER		FOTON		DIESEL		9.19	0.82	297	0	1	0.73
OIL TANKER		FAW		DIESEL		6.12	0.96	317	0	1	0.56
OIL TANKER		NISSAN		DIESEL		10.91	0.93	293	0	1	0.41
OIL TANKER		FAW		DIESEL		7.47	0.96	317	0	1	0.26
OIL TANKER		FAW		DIESEL		11.97	0.98	327	0	1	0.67
OIL TANKER		FAW		DIESEL		11.88	0.75	306	0	1	0.28
OIL TANKER		FAW		DIESEL		7.22	0.81	297	0	1	0.48
PRIME MOVER		FAW		DIESEL		15.32	0.73	265	0	1	0.34
PRIME MOVER		FOTON		DIESEL		12.72	0.63	275	0	1	0.56
PRIME MOVER		FUSO		DIESEL		11.5	0.57	288	0	1	0.51
BOWSER		FAW		DIESEL		8.03	0.78	273	0	1	0.35
OIL TANKER TRAILER		MASTER FOTON		DIESEL		12.93	0.94	275	0	2	0.42
OIL TANKER TRAILER		MASTER FOTON		DIESEL		8.42	0.87	324	0	2	0.59
OIL TANKER		FAW		DIESEL		5.51	0.86	336	0	1	0.67
OIL TANKER		FAW		DIESEL		7.01	0.76	287	0	1	0.51
TOYOTA HILUX		TOYOTA		DIESEL		12.1	0.8	254	0	2	0.64
TRAILER		FOTON		DIESEL		4.85	0.67	282	0	2	0.63
TRAILER		FAW		DIESEL		10.23	0.72	254	0	2	0.52
TRAILER		FAW		DIESEL		11.7	0.67	276	0	1	0.71
LOW BED TRAILER		HINO		DIESEL		10.03	0.66	258	0	1	0.77
MAZDA TRUCK		HINO		DIESEL		15.3	0.99	255	0	1	0.63
20' TRUCK		HINO		DIESEL		9.53	0.75	298	0	1	0.51
MAZDA TRUCK		HINO		DIESEL		11.48	0.76	219	0	2	0.46
TRAILER		DONG FENG		DIESEL		10.94	0.52	243	0	1	0.45
TRAILER		DONG FENG		DIESEL		11.46	0.56	276	0	1	0.77
TRAILER		DONG FENG		DIESEL		15.1	0.53	244	0	1	0.71
40' TRAILER		DONG FENG		DIESEL		14.6	0.57	287	0	1	0.39
40' TRAILER		DONG FENG		DIESEL		11.6	0.56	295	0	1	0.31
40' TRAILER		DONG FENG		DIESEL		12.16	0.53	296	0	1	0.58
40' TRAILER		NISSAN UD		DIESEL		13.1	0.57	294	0	1	0.55
40' TRAILER		HINO		DIESEL		11.6	0.88	298	0	1	0.31
20' TRUCK		SINO		DIESEL		11.54	0.86	299	0	2	0.62
20' TRUCK		SINO		DIESEL		8.83	0.89	239	0	1	0.23
20' TRUCK		ISUZU		DIESEL		11.49	0.78	259	0	1	0.67
40' TRAILER		NISSAN UD		DIESEL		13.57	0.47	268	0	1	0.27
40' TRAILER		NISSAN UD		DIESEL		12.92	0.66	244	0	1	0.57
20' TRUCK		HINO		DIESEL		9.73	0.93	215	0	1	0.47
20' TRUCK		HINO		DIESEL		9.11	0.69	156	0	1	0.59
40' TRAILER		NISSAN UD		DIESEL		7.61	0.68	228	0	1	0.62
40' TRAILER		NISSAN UD		DIESEL		6	0.69	279	0	1	0.24
40' TRAILER		FAW		DIESEL		7.49	0.74	272	0	2	0.44
40' TRAILER		FAW		DIESEL		10	0.91	164	0	1	0.51
40' TRAILER		FOTON		DIESEL		15.62	0.63	293	0	2	0.77
TRACK MOUNTED		SANNY		DIESEL		13.04	0.98	238	0	1	0.29
TRACK MOUNTED		TADANO		DIESEL		14.94	0.68	288	0	2	0.56
ROUGH TERRAIN		TADANO		DIESEL		8.07	0.57	245	0	1	0.67
ROUGH TERRAIN		KOBELCO		DIESEL		12.34	0.49	232	0	2	0.52
TRACK MOUNTED		KATO		DIESEL		10.69	0.62	212	0	1	0.75
TRACK MOUNTED		SANNY		DIESEL		5.39	0.89	275	0	2	0.39
TRACK MOUNTED		KATO		DIESEL		6.29	0.67	235	0	1	0.67
TRACK MOUNTED		KATO		DIESEL		15.37	0.47	297	0	2	0.57
ROUGH TERRAIN		TADANO		DIESEL		9.55	0.72	242	0	1	0.26
WHEEL LOADER		CATERPILLAR		DIESEL		12.85	0.87	234	0	1	0.42
FORKLIFTER		TCM		DIESEL		12	0.66	267	0	1	0.45
TRACK MOUNTED		TADANO		DIESEL		5.46	0.64	261	0	1	0.78
ROUGH TERRAIN		KOBELCO		DIESEL		8	0.65	287	0	1	0.62



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