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Electric Urban Mobility Solution (EUMS) for Indian Market - Personal Mobility - Market Analysis, Vehicle Architecture & Cost Estimation

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Abstract

Urban mobility in India needs restructuring with careful planning to include environmentally sustainable modes of transportation while also taking into consideration the rapid increase of population in urban areas, adverse air pollution, increasing traffic congestion and severe climatic changes compared to a few decades ago. This thesis aims to study the aforementioned conditions to suggest a possible personal urban mobility solution (a quadricycle) for alleviating the adverse situation in urban India while also analysing a suitable price range and favourite attributes for the proposed vehicle from the market (based on a survey curated for this thesis) before proposing a suitable vehicle architecture and a comprehensive cost estimation for the proposed vehicle.

The market analysis chapter aims to understand various factors related to the automobile market, the automobile industry and general problems in urban India that could influence design and engineering parameters of the proposed quadricycle. The chapter gives an overview of various factors and problems from various government reports and private studies to substantiate the aforementioned problems while sometimes providing best practice guidelines to tackle the problems. The chapter also reports on the Indian passenger vehicle market and the Li-ion battery market in India to understand the potential for a new electric quadricycle.

The vehicle architecture chapter discusses various possible features, both technical and comfort features, that the proposed quadricycle could include while also justifying vehicle dimensions and space utilization in an urban environment in comparison to a compact car. The chapter also discusses a survey that was curated for the purpose of gathering opinions of a random group of people in order to determine and understand the opinions of the survey respondents and include the data from the survey into the vehicle architecture, marketing and sales related chapters of this thesis.

The cost estimation chapter aims to understand and quantify the costs of various components and processes to estimate cost of the proposed quadricycle from research papers and other sources; and also calculating a target cost for the proposed quadricycle by comparing prices of various products in the market - both two-wheelers and four-wheelers. The thesis also discusses a few possible business and marketing strategies in brief while also looking into the impact of COVID-19 on the automobile industry and also the future of urban mobility.

List of Abbreviations

EV	Electric Vehicle
GDP	Gross Domestic Product
USA	United States of America
BS4	Bharat Stage 4 (Emission Standard)
BS6	Bharat Stage 6 (Emission Standard)
R&D	Research and Development
cc	Cubic Capacity
FY	Financial Year
PCI	Per Capita Income
SUV	Sports Utility Vehicle
INR	Indian Rupee
NEMMP	National Electric Mobility Mission Plan
FAME	Faster Adoption and Manufacturing of Hybrid and EV
PLI	Production Linked Incentive
CNG	Compressed Natural Gas
PM	Particulate Matter
WHO	World Health Organisation
NO_x	Nitrogen nOxide
CO_2	Carbon Dioxide
L7e	Category for Heavy Quadricycles in India
CGAR	Compounded Annual Growth Rate
MT	Mega Tonnes
CPCB	Central Pollution Control Board
MoEF	Ministry of Environment and Forests
EV	Electric Vehicle
ARAI	Automotive Research Association of India
SMEV	Society of Manufacturers of Electric Vehicles
BEV	Battery Electric Vehicle
HEV	Hybrid Electric Vehicle

PHEV	Plug-in Hybrid Electric Vehicle
FCEV	Fuel Cell Electric Vehicle
E2W	Electric Two Wheelers
E4W	Electric Four Wheelers
OEM	Original Equipment Manufacturer
IEA	International Energy Agency
ICE	Internal Combustion Engine
NBFCs	Non-Banking Financial Companies
EVSE	Electric Vehicle Supply Equipment
AC	Alternating Current
DC	Direct Current
DHI	Department of Heavy Industries
MoP	Ministry of Power
DST	Department of Science and Technology
BIS	Bureau of Indian Standards
CEA	Central Electricity Authority
BEE	Bureau of Energy Efficiency
DISCOMS	Distribution Companies
GST	Goods and Services Tax
EESL	Energy Efficiency Services Limited
EOI	Expression of Interest
UN	United Nations
PPP	Public Private Partnership
CAPEX	Capital Expenditure
USP	Unique Selling Proposition
WLTP	Worldwide Harmonized Light-duty Vehicles Test Procedure
IP	Instrument Panel
PV	Photovoltaic
LED	Light Emitting Diode
LCD	Liquid Crystal Display
oLED	Organic Light Emitting Diode

5G	Fifth Generation mobile network
4G	Fourth Generation mobile network
C-V2X	Cellular Vehicle-to-Everything
OS	Operating System
IP	Internet Protocol
i.MX	IP Multimedia Exchange
eMMC	Embedded Multi-Media Card
LPDDR	Low Power Double Data Rate
LTE	Long Term Evolution
WiFi	Wireless Fidelity
BT	Bluetooth
DSRC	Dedicated Short Range Communication
eUICC	Embedded Universal Integrated Circuit Card
GPS	Global Positioning System
GLONASS	Global Navigation Satellite System
HSM	Hardware Security Module
Gbit	Giga bit
CAN	Controller Area Network
USB	Universal Serial Bus
GB	Giga byte
SIM	Subscriber Identification Module
HVAC	Heating Ventilation and Air Conditioning
GHz	Gigahertz
ABS	Anti-lock Braking System
ESP	Electronic Stability Program
Li-ion	Lithium Ion
OCV	Open Circuit Voltage
SOC	State of Charge
$LiCoO_2$	Lithium Cobalt Di-oxide
C	Carbon
SOC	State of Charge

IPMSM	Interior Permanent Magnet Synchronous Motor
IM	Induction Motors
PMa-SynRM	Permanent Magnet Assisted Synchronous Reluctance Motor
DC	Direct Current
PDU	Power Distribution Unit
G2V	Grid-to-Vehicle Interaction
V2G	Vehicle-to-Grid
OBC	Onboard battery chargers
CC/CV	Constant-current / Constant-voltage
FCS	Fast Charging Stations
VCU	Vehicle Control Unit
VCS	Vehicle Control System
EMCS	Electric machine control system
SCS	Stability control system
BMS	Battery management system
DMS	Driver mode system
HVAC	Heating ventilation and air conditioning
EVI	Economised Vapour Injection
GWP	Global Warming Potential
VCR-DH	Vapour compression refrigeration - Dedicated heating
VC-HP	Vapour Compression heat pump
VC	Vapour Compression
VCR-EH	Vapour compression refrigeration - Electric heating
VCR-FH	Vapour compression refrigeration - Fuel Heating
TES	Thermal energy storage
TE	Thermoelectric
ME	Magnetic effect
WHD	Waste heat driven
ITM	Integrated thermal management
COP	Coefficient of Performance
IC	Internal Combustion

ABS	Anti-lock Braking System
ESP	Electronic Stability Program
COVID-19	Coronavirus disease of 2019
REVA	Revolutionary Electric Vehicle Alternative
SG&A	Selling, Governance and Administrative
BIW	Body in White
ESP	Electronic Stability Program
RC	Registration Certificate
e.g.	Example
UIDAI	Unique Identification Authority of India
eVTOL	Electric Vertical Take-off and Landing
CES	Consumer Electronics Show
GM	General Motors

List of Units

km	Kilometre
cc	Cubic Capacity
kW	KiloWatt
kWh	KiloWatt Hour
GWh	GigaWatt Hour
µg/year	Microgram per year
℃	Degree celsius
kg	Kilogram
v	volt
MW	MegaWatt
GW	GigaWatt
mm	Millimetre
m^2	Square metre
Nm	Newton metre
N	Newton
m	Metre
W	Watt
J	Joule
s	Seconds
θ	Angle
ω	Angular velocity
Whr/kg	Watt-hours/kilogram
Whr/L	Watt-hours/litre
kg	Kilogram
GHz	GigaHertz
kHz	KiloHertz
Hz	Hertz
W/m^2	Watt per square metre
V	Volt

List of Symbols

M	Torque
F	Force
r	Radius-vector
s	Displacement
P	Power
A	Work
t	Time
F_D	Drag Force
ρ	Density of the fluid
v	Speed of the body relative to the fluid
C_D	Drag coefficient
A	Front cross-sectional Area
η	Efficiency of electric motor
P_1	Input power
P_2	Useful output power
J	Moment of inertia
m	Mass
L	Armature inductance
R	Armature resistance

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Introduction

With the rise of tech companies after a high rate of smartphone penetration, a need for efficient smartphone integrated design has started emerging across almost all consumer industries. This is also true for the automotive sector, where Apple Carplay and Android Auto have become essential features in all vehicles. While in the automotive sector, focus is now on technology-aided efficient mobility that is supported by an increase in market capital of electric vehicle companies like Tesla and ride sharing apps like Uber and Ola.

Tesla, which is also considered as a tech company, had its valuation increase to a point where market capitals of giant carmakers with more than 100 times in sales numbers than Tesla were dwarfed in comparison. And companies like Uber and Ola are considered to be the largest mobility solution providers even when Uber does not use its own vehicles. That being said, micro-mobility is considered to be a sector with a lot of potential and small vehicles will play a crucial role in urban mobility needs of the future.

With these trends in mind, in the future it would be necessary to have a product that could cater to both personal vehicle ownership and also for car sharing needs. Such a vehicle will need to be small, electric, affordable, yet for a private user - customisable to personal tastes and must have a great design. Even though this thesis focuses on the Indian Market, the proposed quadricycle could be a global product. This thesis analyzes the various aspects for introducing a Category L7M (Heavy Quadricycle) Electric Vehicle for use in an urban environment.

The thesis aims to understand the Indian automobile market and to analyse the marketing survey specifically curated for this project and to finally combine research, theory and the survey results to define the ideal vehicle architecture, to make a cost estimation, to suggest a target price and also to discuss various possible marketing strategies for the quadricycle. Secondly, the thesis aims to support the ideal vehicle architecture defined with regulations in the Indian market and to compare similar vehicles in the global market with focus on innovation, safety and practicality. The cost estimation of such a vehicle is done considering various researches, reviews and listing spare parts costs of a reference vehicle to check if we can meet the defined target price.

1. Market analysis

The $118 billion global automobile industry is expected to reach $300 Billion by 2026. India's annual production has been 30,91 million vehicles (total production) in 2019 as against 29,08 million in 2018, registering a healthy growth of 6,26%. [17]

India is projected to be the world's third-largest passenger-vehicle market very soon. It took India around seven years to increase annual production to four million vehicles from three million, but the annual production mark of five million vehicles is expected to reach sooner than seven years. Urbanization, increasing purchasing power of people, supportive regulations and policies are all factors contributing to this growth. Taking into account the aforementioned factors it is possible to create a perspective on the trends shaping the Indian automobile market, the value proposition for the automobile industry in India, and qualities for winning in the market.

The present categories in the Indian automobile sector as per their market share in 2019 - 2020 comprises of Four-wheelers (2.773.575 Units), Commercial Vehicles (717.688 Units), Three-wheelers (636.569 Units), Two-wheelers (17.417.616 Units) and Quadricycles (942 Units) as depicted in Figure 1.0.1. [9]

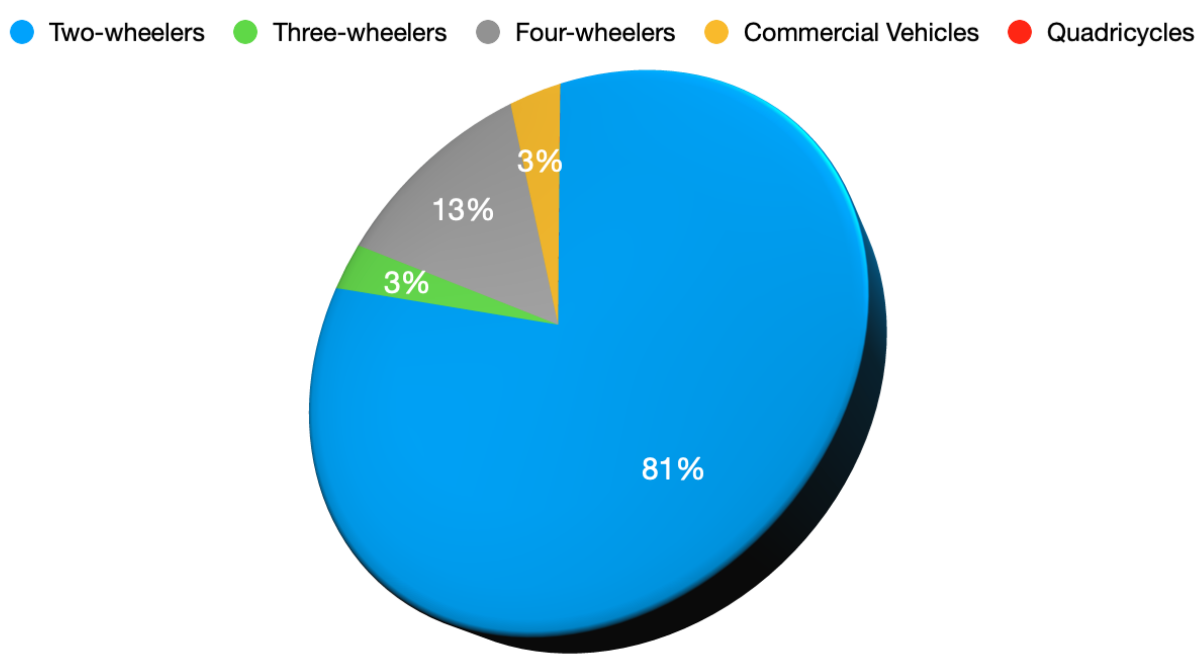


Figure 1.0.1: Representation of market share by category for automobiles (2019-2020)

From Figure 1.0.1, the numbers clearly point to a high disparity in market share of two-wheelers in comparison to other segments, especially four-wheelers with regards to this thesis. In general, this disparity with four-wheelers is not because of "customer choice", but rather because of "difference in purchasing power of the customers". Even though it is possible to generalize that four-wheelers are more preferred than two-wheelers, there are various other factors other than purchasing power that contribute to this disparity. And in the coming years with increasing per capita income and improving living standards, an increase in market share of four-wheelers is expected. And as of 2020, both these segments cater to the majority of personal mobility needs of the population in India.

It is important to note that quadricycles are a new segment and the market share of quadricycles will increase significantly with more products and better solutions in the near future; and with a new, innovative and desirable product, it would be possible to gather customers from both the upper price band of two-wheelers (greater than 250cc engine capacity) and the lower price band of four-wheelers (less than 1200cc capacity). Further reasons and scenarios for wider adoption of such quadricycles shall be discussed in detail in the following paragraphs of this thesis.

Why are quadricycles important for India?

Approved by the Ministry of Road and Highways in 2018, "Quadricycle" is a new category for automobiles in India [22]. As per reports, the global market value of quadricycles stood at $347 million in 2019 and is expected to display a CAGR of 2,0% from 2020 to 2027 [16]. However, this CGAR could be substantially more in India with more products and favourable policies being curated for the category in the following years.

Also important to note is that in Europe the minimum age requirement to drive a quadricycle is 16 years [23]; even though in India, one can only ride an electric motorbike if they are 16 years old; this rule could be amended in the future to include quadricycles. This particular amendment could open up a new market for quadricycles in India.

And since quadricycles are much safer than motorbikes in every aspect, the category could be the default choice for a significant number of customers. This argument can be validated by a report from the Ministry of Road and Highways in 2019 [24]:

India ranks at number 1 in the list of number of road accident deaths in the 199 countries mentioned in the World Road Statistics, 2018; India is followed by China and the USA. India accounts for almost 11% of the accident related deaths in the world as per the WHO Global Report on Road Safety 2018. [24]

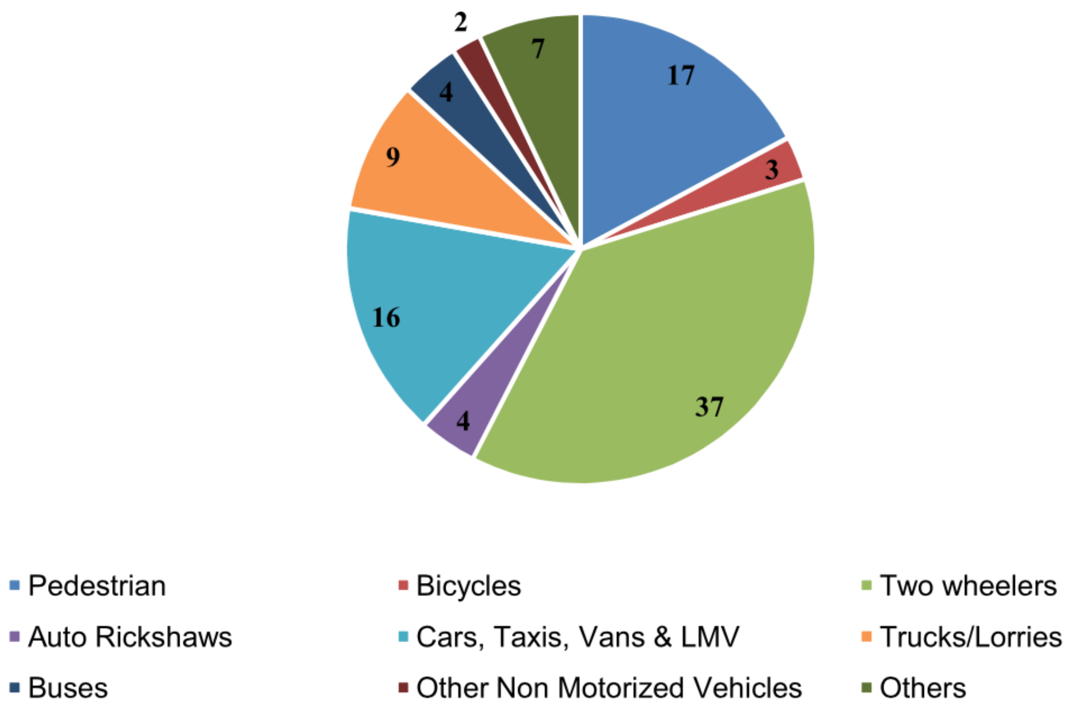


Figure 1.0.2: Percentage share of people killed by category of vehicle involved in accident [24]

Out of the total 151.113 deaths by road accidents in 2019, 56.136 deaths involved two-wheelers [24]. From the Figure 1.0.2 above, this is almost 37% of the total deaths and more than twice the share of deaths involving a four-wheeler. Hence, quadricycles could be much safer, if not twice as safe than a motorbike, with safety regulations comparable to that of four-wheelers.

1.1. Indian passenger-vehicle market

As the automobile market is projected to see a constant increase in the number of vehicles sold in the country, the passenger vehicle market (both two-wheelers and four-wheelers included) is projected to be the segment that will see a significant increase in sales numbers in the coming years. This increase could be predicted by considering the following reasons:

Favorable macroeconomic and demographic trends

In 2018, the automotive sector contributed more than 7% to India's GDP. The Automotive Mission Plan 2016 – 2026 by the Government of India sets an aspiration to increase the contribution by the automotive sector to India's GDP to 12%. There are a number of economic trends that could help in meeting this target. [21]

Rapid urbanization in the country will lead to having over 500 million people living in cities by 2030, which is 1,5 times the current population of the USA. Rising income will also play a role in increasing vehicle demand [25], as roughly 60 million households could enter the consuming class (defined as households with incomes greater than $8.000 per annum in India) by 2025. At the same time, more people will join the workforce with an increasing number of women and youth entering the job market, raising the demand for mobility. Some of these people would leap straight into the four-wheeler segment, and others would move from their existing two-wheelers to four-wheelers. Figure 1.1.1 from a study [25] shows us the relation between per capita income (₹) and per capita vehicles, validating the argument of increase in number of vehicles with data from 1961 till 2015 that can be extrapolated for 2021.

The study [25] also compares the per capita vehicles to urban population with the per capita vehicles to working population in Figure 1.1.2. It is interesting to note that the per capita vehicles in urban India is more than the per capita vehicles for the whole of India (as seen in Figure 1.1.1) while the cities are home to about 40% of the total population; and support almost 183 million vehicles on narrow and highly congested roads.

Even though there is rapid public transportation development across all major cities, improvement in standard of living is also increasing the demand for personal mobility vehicles. Compact cars and hatchback cars have been the majority of sales in the automobile industry in

India, with a share of around 50%. These segments will continue to maintain a dominant position, but the majority of growth is expected to come from new segments such as compact SUVs, sedans, luxury vehicles and other new categories.

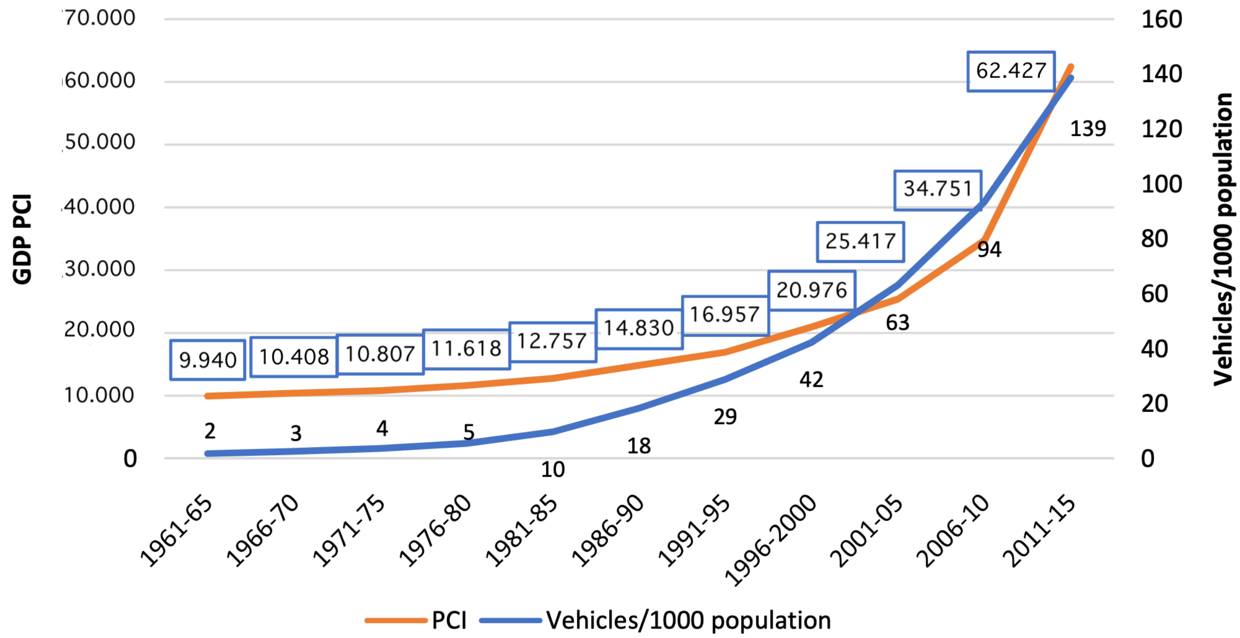


Figure 1.1.1: Per capita vehicles and per capita income (₹) in India for the Period 1961-2015

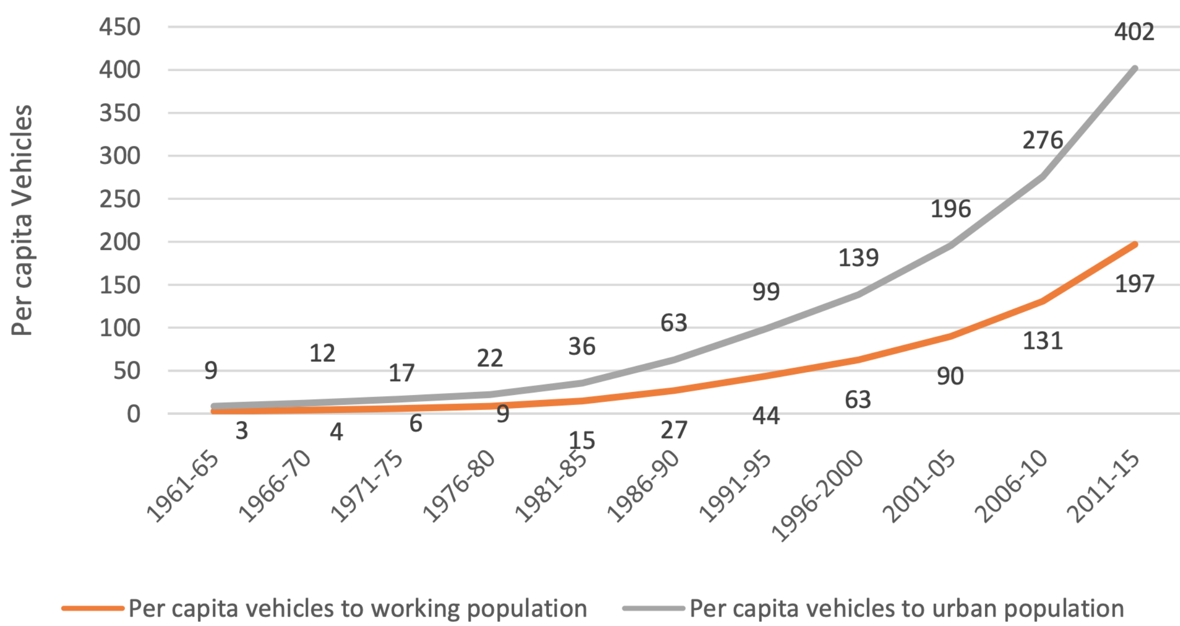


Figure 1.1.2: Per capita vehicles and urban population in India

Continued government focus on supporting the industry

By introducing the Automotive Mission Plan, the National Electric Mobility Mission Plan (NEMMP), the Faster Adoption and Manufacturing of Hybrid and EV (FAME) scheme and various other initiatives, the government seeks to achieve two objectives - facilitate long-term growth in the industry and reduce emissions and oil dependence [21][17].

Strict enforcement of new emission targets has enabled India to leapfrog from BS4 emission standard to BS6 emission standard (Euro 6 emission standard equivalent) in 2020. Additionally, India has implemented Corporate/Fleet average fuel efficiency norms in which the manufacturers have to improve their fuel efficiency by 10% between 2017 and 2021 and by 30% or more from 2022 [21][17].

The government has also introduced an voluntary end-of-life or scrappage policy to vehicles over 15 years of age (for personal vehicles) to monitor emissions from old vehicles and to increase sales of new vehicles. This policy also enables one to get a 5% rebate on the purchase of a new car after scrapping the old one [21][17].

Development of India as a manufacturing hub

The World Economic Forum ranks India as 30th on the global manufacturing index among more than 100 countries. The Indian government's "Make in India" initiative has played an important role in elevating the country's position on the global manufacturing index. Also, in the past years, India has improved on nine out of ten parameters for ease of doing business. India accounts for 40% of the total $31 Billion of global engineering and R&D spend. 8% of the country's R&D expenditure is in the automotive sector [17][21].

"Atmanirbhar Bharat Abhiyaan" (Self Reliant India) scheme that was recently introduced by the Government of India allocates a special economic and comprehensive package of $274 billion that aims to promote manufacturing in India. The Production-Linked Incentive (PLI) Scheme allocates a financial outlay of $6,9 billion to the Automobile sector under the Atmanirbhar Bharat scheme. This scheme again aims to promote manufacturing more automobiles in India [17][21]. In addition to this, India will be the youngest nation in the world by 2025 with an average age of 25 years which can significantly contribute to having a healthy and energetic workforce to meet labour needs in the manufacturing sector [17].

1.2. Major problems for urban mobility in India

Urban mobility in India has a number of problems because the rate of infrastructure development was not in proportion to the increasing mobility needs of people. This is evident with the increase in traffic density and the time taken to travel in urban areas today. But with the new government focus on infrastructure development since the early 2000s, this need for urban mobility is being addressed with new shared mobility solutions like Metro lines in all major cities and alternative energy powered public buses (both electric and CNG powered) to name a few. However, personal mobility has always been restricted to taxis and four-wheelers; and with increased pollution levels and deteriorating air quality, two-wheelers and bicycles are becoming difficult to use for daily personal commute. Some of the major urban mobility problems in India that are common to the major cities are:

Increasing Traffic density

According to a study conducted to understand mobility and congestion in 154 cities in India, there is a wide variation in travel times across the cities. The study has used satellite mapping softwares like Google Maps and others with special focus on Central Delhi (the National Capital Region) for analysing the traffic flow and commute times. This variation in time taken to travel from point A to point B can be because of congested mobility, uncongested mobility, density of population and various other factors. [1]

The study also suggests that traffic congestion is not a nationwide problem, but rather more localised and near the city centers. Increasing congestion, population density, urban land cover and per capita cars in urban areas play important roles in increasing travel times especially near city centres and during office commute hours.

The Figure 1.2.1 below shows the result of the study as a graphical representation. It is interesting to note that Central Delhi (the National Capital) recorded the largest increase of upto 40% increase in travel time during peak hours (usually business hours), while the 154 cities in the study including Central Delhi had an average increase of a little more than 10% travel time during peak hours. However the 20 largest cities in India had an average increase in travel time of upto 25% during peak office hours.

The study also compared travel times obtained in India with other cities in the world and found that the fastest Indian cities in terms of travel times are slower than the slowest cities in the USA. This is clearly a pointer to improve the traffic policies to better manage the traffic flow and time delays for travel.

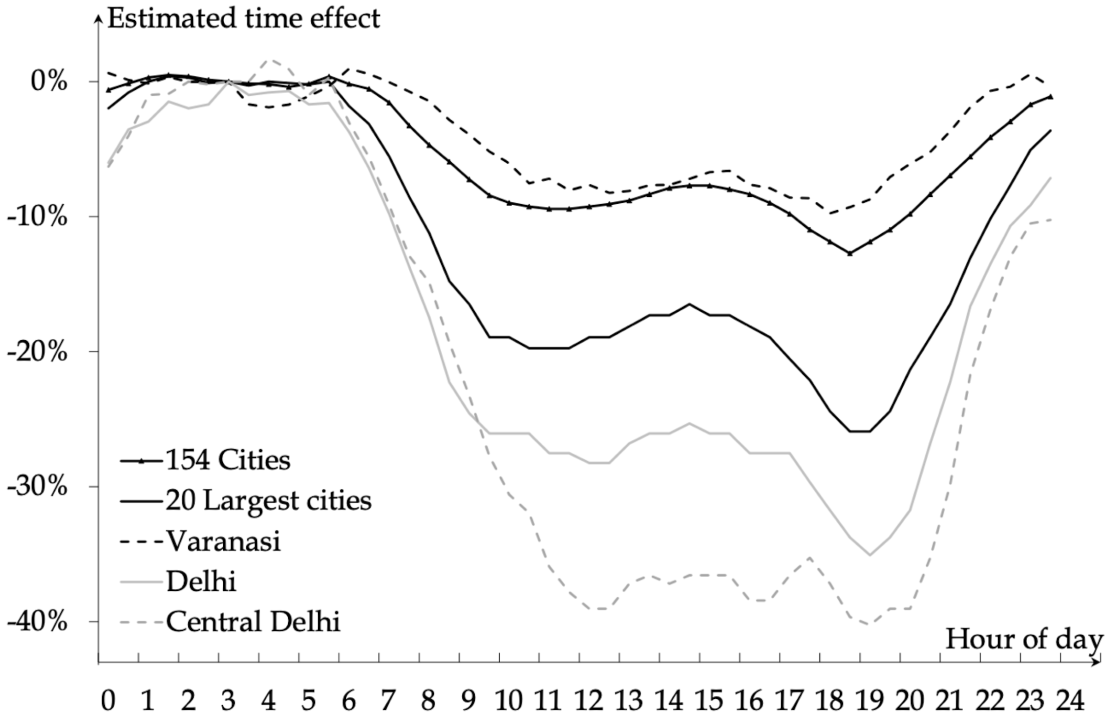


Figure 1.2.1: Estimated time effects for weekday travel in Major Urban Areas in India [1]

Another study [25] about Income and Vehicular growth in India points out that the rate of development of road infrastructure in India is not proportional to the growth rate of vehicles in the country and is almost inversely proportional, as seen in Figure 1.2.2 from the study. It would be possible to assume that the growth rate of roads in urban areas are much less than the average national growth rate due to land area limitations and population density while the per capita vehicles are increasing.

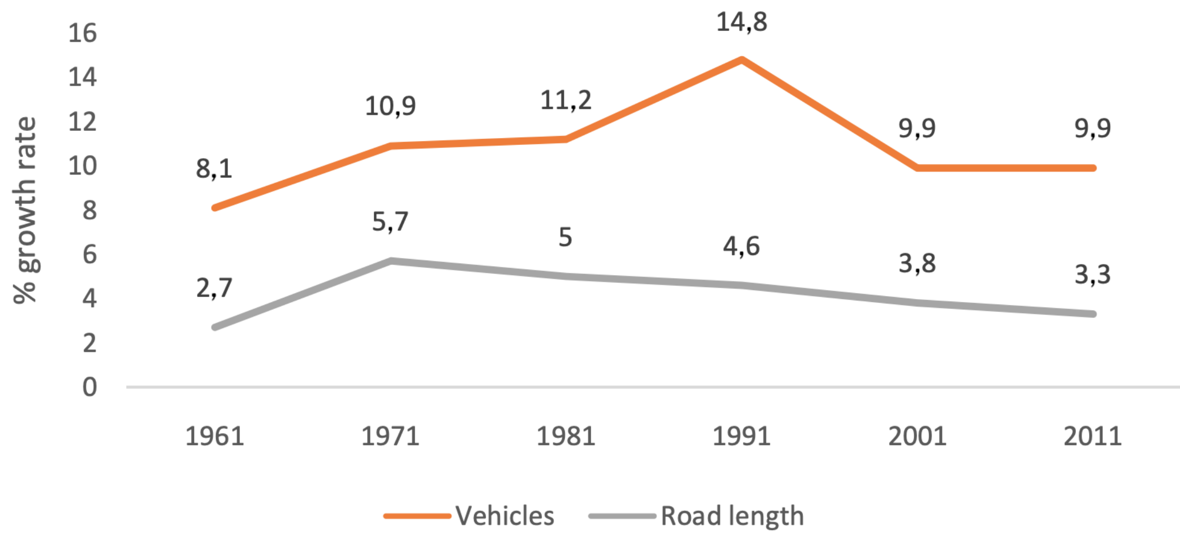


Figure 1.2.2: Percentage growth Rate of Vehicles and Road Length in India [25]

This intensity of traffic congestion is evident in the urban areas of India, due to the exponential growth of vehicles and a low increase in the road length, especially in the past two decades. From Table 1.2.1, the road space available for vehicles is decreasing at a very high rate, from 0,18 kms per vehicle to 0,01 kms per vehicle from 1971 to 2011; this has created a huge pressure to accommodate newer vehicles into existing and over utilised urban road infrastructure. [25]

Road Length & Vehicles	**1971**	**1981**	**1991**	**2001**	**2011**
Urban road length (kms)	72120	123120	180799	252001	411840
Registered vehicles (million)	1,9	5,7	21,4	55	141,9
Road space for vehicles (in kms per vehicle)	**0,18**	**0,1**	**0,03**	**0,02**	**0,01**

Table 1.2.1: Decade wise urban road length [25]

Overcrowded public transport infrastructure

Cities in India are becoming overcrowded every year with a large population in flow from smaller towns and villages for employment and business purposes. The number of cities in India with a population greater than 1 million increased from 35 to 53 between 2001 and 2011 (Census-India 2012, Census is conducted once every 10 years). Out of the total urban population living in about 8000 towns in India, more than 40% live in the 53 largest cities. The number of cities and the population in cities are increasing overtime with growing businesses and the government's plan for rapid urbanisation across India. [2]

According to the report investigating the association between population density and travel patterns in Indian cities [2], cities with population density greater than 80 persons per hectare are not likely to have better usage of public transport modes. Figure 1.2.3 below shows that most cities in India have a population density greater than 80 persons per hectare and hence one could say that the public transport systems are likely to be overcrowded during the peak office hours. And this has been the case in all the major cities across India, where commuting to work is becoming increasingly difficult and is forcing people to move to private means of transport as per reports [12].

And if the trend of shifting mobility from public transport to private transportation continues, the existing road infrastructure would be inadequate and will lead to more traffic congestion in urban areas. This argument is further validated by Figure 1.2.1 which defines the decreasing road space for vehicles in urban areas with every decade, and is very likely to reduce by at least half in 2021 considering the trend from 2001 to 2011. And this reducing road space for vehicles is going to slow down both public and private vehicles on urban roads.

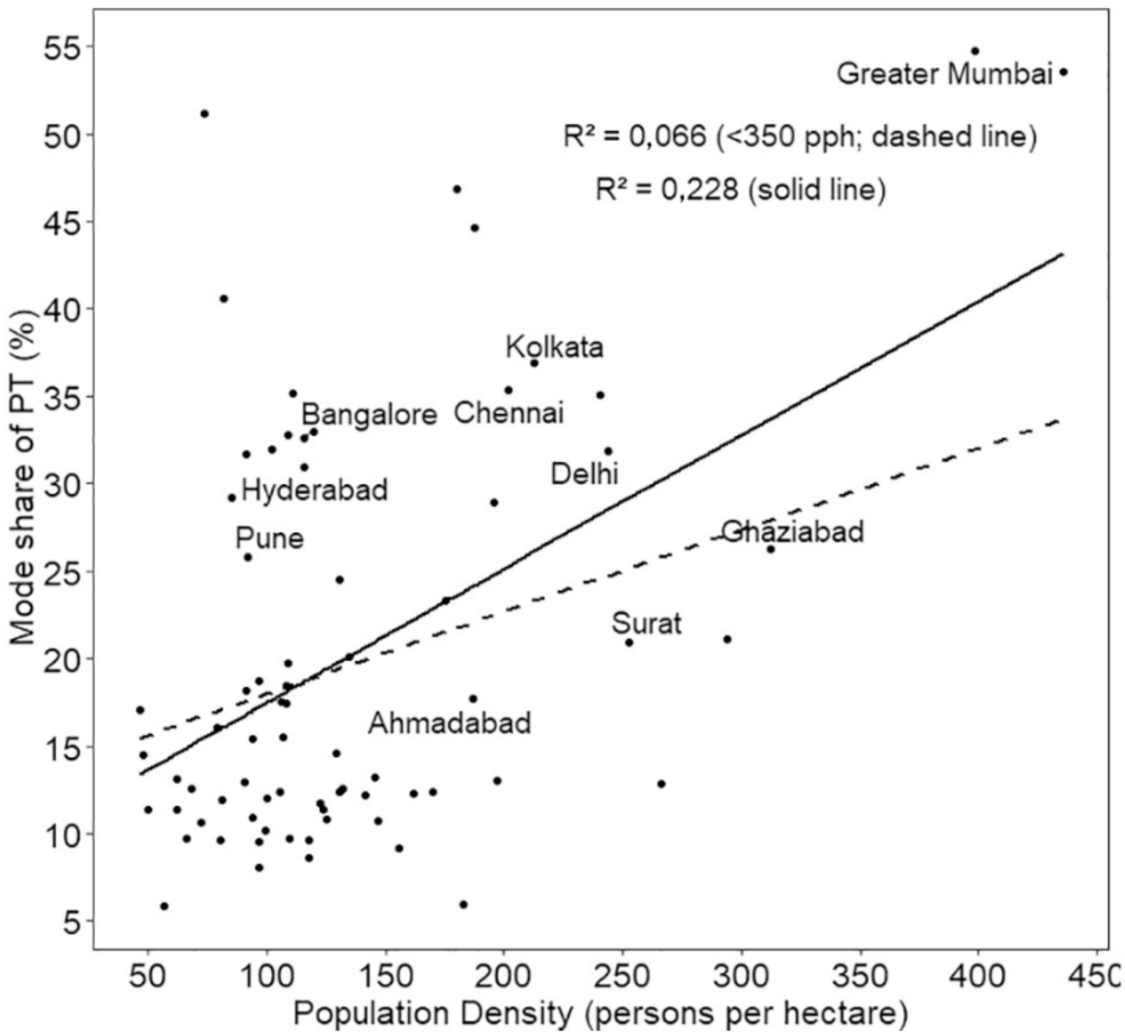


Figure 1.2.3: Mode share of Public Transport (PT) with respect to population density [2]

Increasing pollution levels

The air pollution in urban areas is becoming toxic with an increasing number of petroleum powdered vehicles on the road as the data shows that $PM_{2.5}$, PM_{10} , NO_x , CO_2 levels and Energy Consumption per trip in urban areas are increasing [12] and so are the number of cars on the roads. These increasing levels of pollution are causing serious health problems among the urban population and in some extreme cases, continuous exposure to pollutants may even cause death. Traffic-related air pollution leads to cardiovascular morbidity, asthma incidence and other respiratory illnesses in children. [25]

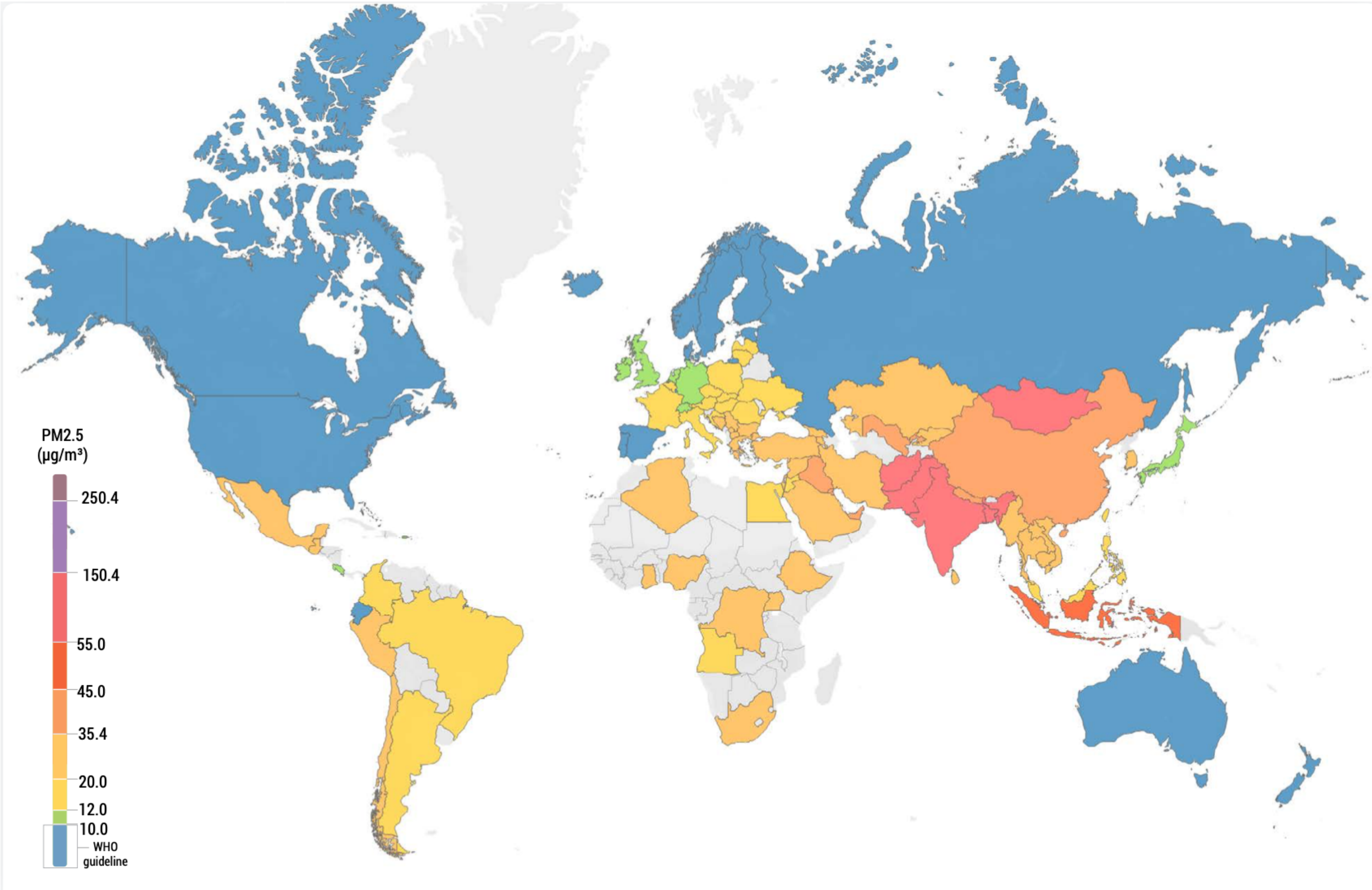


Figure 1.2.4: Global map of estimated $PM_{2.5}$ exposure by country/region in 2019 [3]

According to a study about income and vehicular growth in India, the transport sector is the major contributor to air pollution in the country. But among the different modes available in the transport sector, road transportation mode is the major cause of CO_2 emissions in India. The average emission of CO_2 from the transport sector was estimated to be 14% of the total during the period of 1971-2013 (World Bank, 2013). Among total emissions by the transport sector (142MT of CO_2) , the road sector alone contributed 87% of emission in 2011 (MoEF, 2011). [25]

Particulate matter (PM) is one of the major sources of air pollution from vehicular emissions. According to WHO (in 2008), around 600.000 people die prematurely each year in the world from diseases directly related to air pollution. The global burden of disease (by WHO in 2011) report listed ambient air pollution as the 6th important cause of death in South Asia. Another study supported by WHO estimated that 154.000 people died in India in 2005 as a result of ambient fine particulate matter ($PM_{2.5}$) (NTDPC, 2014). [25]

According to the 2019 World Air Quality Report [3] that focuses on $PM_{2.5}$ concentrations ($PM_{2.5}$ pollutant is considered for the report as it is widely regarded as most harmful to human health), out of the top 30 most polluted cities in the world, 21 are from India. Even though this is not a favourable situation for India, the government has been taking adequate measures to curb the increasing pollution levels related to transport at various levels including policies.

Central government actions include creating new smart city policies, transit-oriented development policies, national habitat standards for transport, service-level benchmarks for bus transport, decongestion plans for cities like Delhi, etc. Many state governments have also adopted new strategies and policies to modernize and expand to environmentally friendly public transport, carry out infrastructure development for non- motorized transport, and enforce better street design guidelines and improve elements of parking policy [12]. However, in order to decrease pollution in urban areas in the short term, the government will have to increase the adoption of electric vehicles in urban areas.

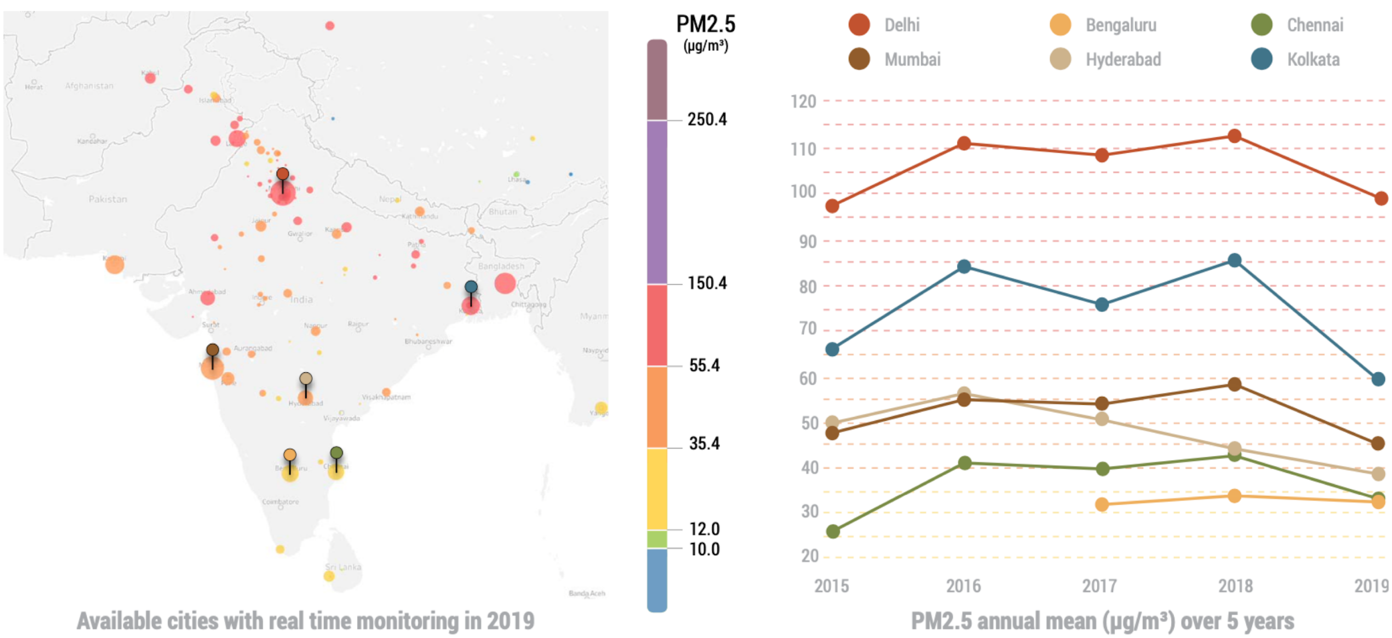


Figure 1.2.5: Estimated $PM_{2.5}$ levels across various cities in India [3]

The estimated $PM_{2.5}$ levels across various cities in India are represented in the graph on the right of Figure 1.2.5 and the $PM_{2.5}$ exposures obtained are above the WHO recommended exposure limit of less than 10µg/year. Delhi remains on the top of the chart on the right with the highest level of $PM_{2.5}$ pollutant and Bengaluru is at the bottom of the chart with a little more than 30µg/year $PM_{2.5}$ pollutant.

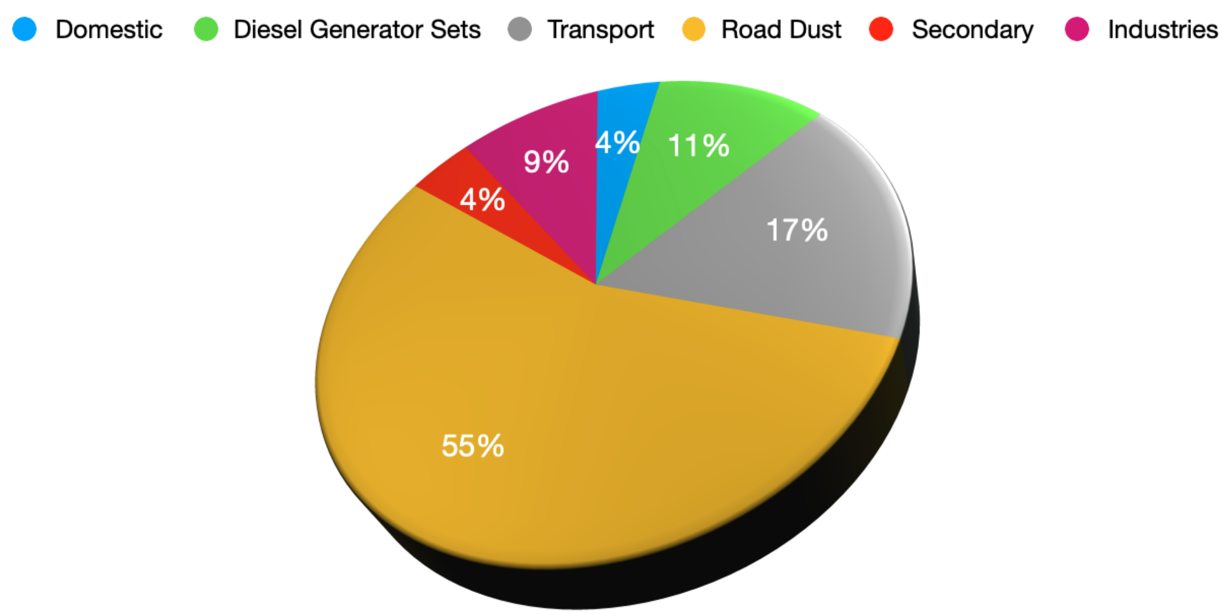


Figure 1.2.6: Sources of particulate pollution in India in 2011 [25]

Also in the study [25], the Central Pollution Control Board (CPCB), Ministry of Environment and Forest (MoEF) in 2011 jointly conducted a research on modelling and analysing particulate pollution in the country; as seen in Figure 1.2.6, the study reveals that transport and road dust are the major sources of particulate pollution in the country (upto 72%) and this figure has been increasing with increasing number of vehicles in urban areas. Also the increasing particulate emissions are creating a health hazard for the population, more so in urban areas than the rest of India.

Adverse climatic conditions

India is one of the most vulnerable countries in the world to climate change (based on projections) and also a major greenhouse gas emitter. The impacts of this climate change in the country includes water shortage, heat waves, severe storms, flooding and associated negative consequences on health and livelihoods. With a growing population of 1,2 billion and dependence on agriculture, India probably will be severely impacted by continuing climate change. Global climate projections indicate several changes in India's future climate [36]:

1. Global observations of melting glaciers suggest that climate change is under way in the region, with glaciers receding at an average rate of 10 - 15 meters per year. If the rate increases, flooding is likely in river valleys fed by these glaciers, followed by diminished flows, resulting in water scarcity for drinking and irrigation.

2. All models show a trend of general warming in mean annual temperature as well as decreased range of diurnal temperature and enhanced precipitation over the Indian subcontinent. A warming of 0,5℃ is likely over all of India by the year 2030 (approximately equal to the warming over the 20th century) and a warming of 2 - 4℃ by the end of this century, with the maximum increase over northern India. Increased warming is likely to lead to higher levels of tropospheric ozone pollution and other air pollution in the major cities.

3. Increased precipitation (including monsoonal rains) is likely to come in the form of fewer rainy days but more days of extreme rainfall events, with increasing amounts of rain in each event, leading to significant flooding (already taking place in various places). Drizzle-type precipitation that replenishes soil moisture is likely to decrease. Most global models suggest that the Indian summer monsoons will intensify. The timing may also shift, causing drying during the late summer growing season. Climate models also predict an earlier snowmelt, which could have a significant adverse effect on agricultural production. Growing emissions of aerosols from energy production and other sources may suppress rainfall, leading to drier conditions with more dust and smoke from the burning of drier vegetation, affecting both regional and global hydrological cycles and agricultural production.

The capacity to adapt to various climates in India varies by state, geographical region, and socioeconomic status. Studies point to influential factors such as water availability, food security, human and social capital, and the ability of government (state and national levels) to buffer its people during tough times. Where adaptive capacity is low, the potential is greater for impacts to result in displaced people; deaths and damage from heat, floods, and storms; and conflicts over natural resources and assets.

According to the study by Joint Global Change Research Institute and Battelle Memorial Institute, Pacific Northwest Division [36], Figure 1.2.7 depicts the various climate regions and conditions in India at the time of the study. Table 1.2.2 discusses in detail the various climate types with maximum and minimum temperatures in those regions at the time of the study. However, it is important to point out that temperatures have increased significantly to have daily peaks of significantly over 40℃ across most parts of India [38] and these high temperatures in combination with humidity (like in various metros situated in the vicinity of the Indian Ocean and the Bay of Bengal Sea) is not a pleasant situation.

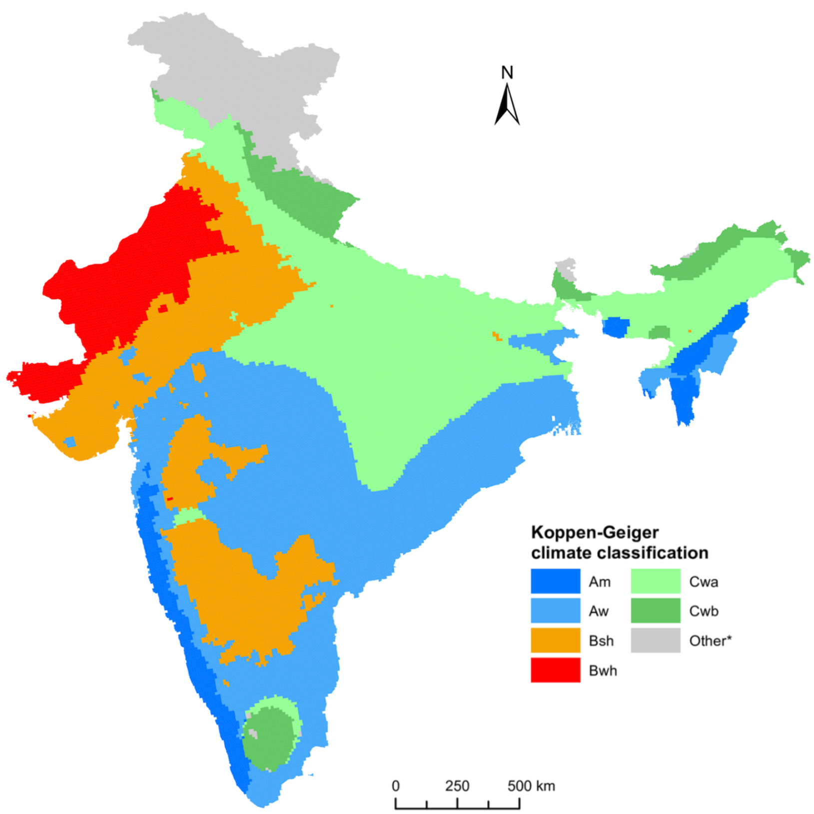


Figure 1.2.7: Climate regions and conditions in India [36]

		Summary of daily mean temperature (°C)		
Climate region	**Climate condition**	**Average (Minimum; Maximum)**	**Standard Deviation**	**Number of medical deaths**
Am	Equatorial Monsoon	25,13 (10,58 ; 34,31)	3,18	39.783
Aw	Equatorial Savannah with dry winter	26,46 (10,32 ; 39,73)	4,02	135.263
Bsh	Hot steppe climate	26,01 (2,04 ; 39,65)	5,13	79.783
Bwh	Hot desert climate	26,01 (6,42 ; 39,20)	6,13	10.713
Cwa	Warm temperate climate with hot summer and dry winter	24,55 (0,40 ; 39,73)	5,78	126.201
Cwb	Warm temperate climate with warm summer and dry winter	22,79 (1,07 ; 35,90)	5,57	19.870
India	-	25,14 (0,40 ; 39,73)	5,16	**411.613**

Table 1.2.2: Climate conditions for various regions in India 2009 [36]

1.3. An electric quadricycle for India

Considering the arguments and research presented in the previous paragraphs of this thesis, it can be derived that the ideal personal mobility solution for urban areas in India should be small, to have a smaller footprint on the road than conventional compact car; fully electric (BEV), to control the local pollution levels; safer than a motorcycle, to reduce injuries to occupants if an accident occurs and cost less than a compact car, for wider adoption. More characteristics of such a quadricycle will be discussed in detail in the chapter of this thesis - Vehicle architecture.

In order to understand the urban mobility preferences of people in India, a survey was conducted, the results of which we shall discuss in the following paragraphs. This section will cover

Survey for an electric quadricycle in India

The survey had over 400 respondents, most of whom are residents of India or of Indian origin and almost 90% have owned a vehicle or plan on owning a vehicle in 5 years' time (Figure 1.3.1); and almost 72% of the correspondents were open to purchasing an electric vehicle (Figure 1.3.2). It is also interesting to note that the respondents of our survey were more male than female, almost 70% male and 30% female as seen in Figure 1.3.3 below.

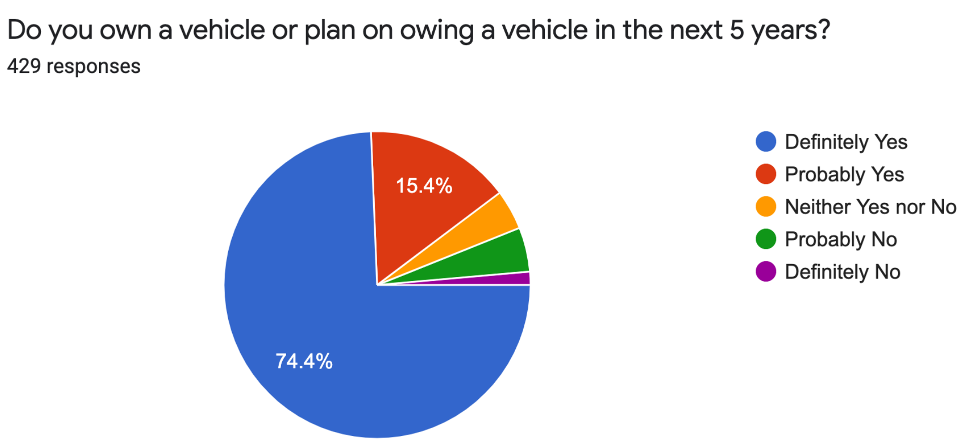


Figure 1.3.1: Survey results - vehicle ownership prospects

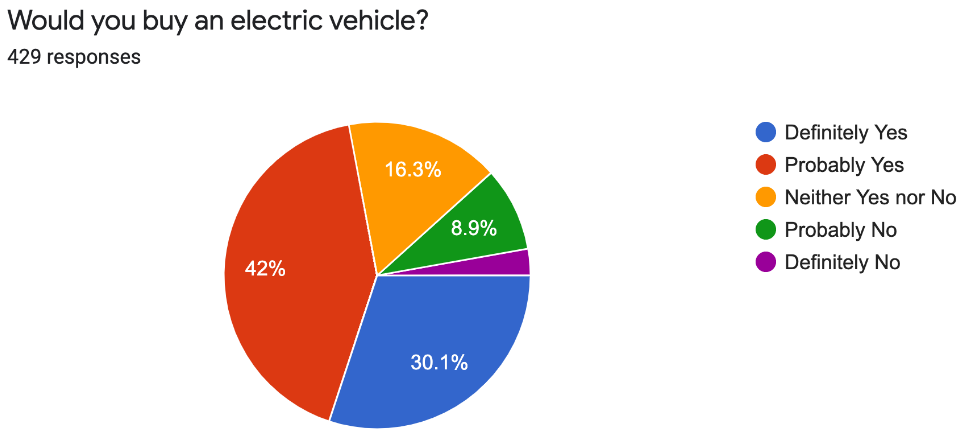


Figure 1.3.2: Survey results - electric vehicle ownership prospects

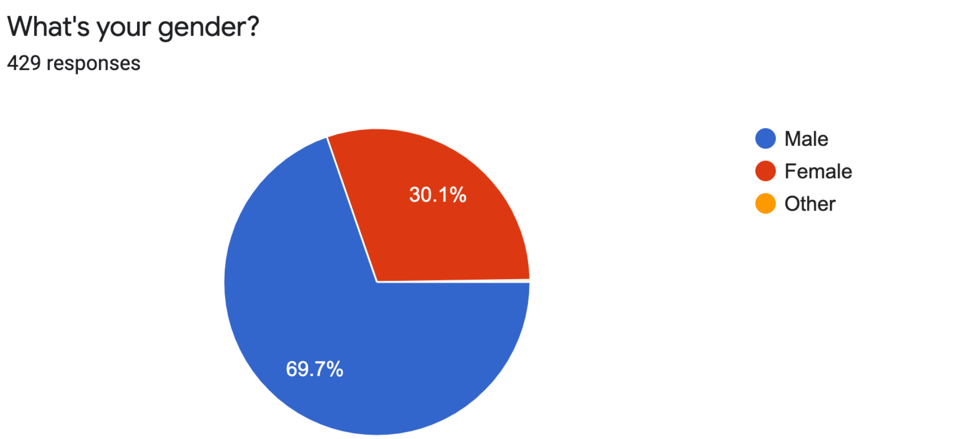


Figure 1.3.3: Survey results - gender of respondents

The respondents were of various age groups, however we wanted to focus more on the age group of 16 to 25 years as this is the legal age for riding a motorcycle in India; and it is expected that 16 years would also be the minimum age to legally drive a quadricycle in India in the near future following the trend in several European countries (at present the legal age for driving a four-wheeler in India is 18 years or above). Once this amendment comes into effect, the age group between 16 and 18 years of age will be a new market for a quadricycle. And almost 60% of our respondents are between the ages of 16 and 25 years as seen in Figure 1.3.4 below.

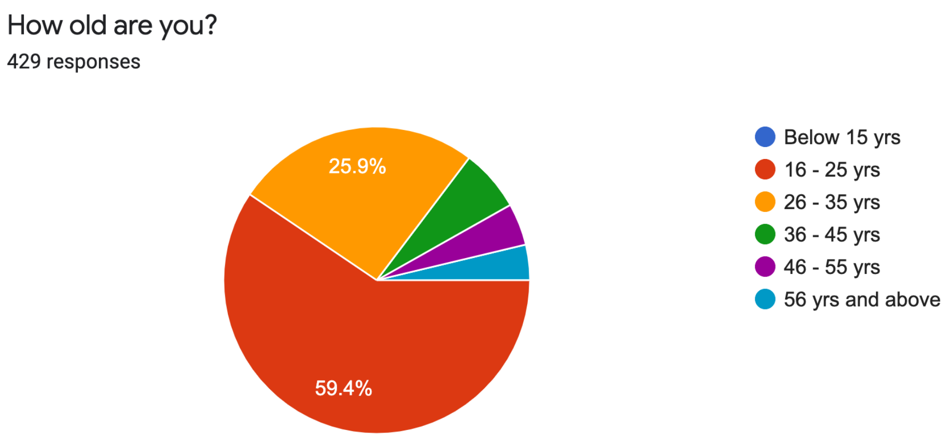


Figure 1.3.4: Survey results - age of respondents

Inorder to estimate the preferred maximum range for an urban commute vehicle, the daily commute distances of the respondents was asked and Figure 1.3.5 shows the results obtained. It is interesting to note that over 60% of the respondents travel upto 20 kms everyday and this result is inline with results obtained by Centre for Science and Environment, New Delhi in one of their studies to understand urban commute [12] as shown in Figure 1.3.6. Taking this information as a pointer and extrapolating the results for 7 days, factoring in range anxiety, range depletion and other factors, it would be safe to estimate the maximum ideal range as 200 kms. Infact, our survey also asked the respondents for their preferred maximum range and almost 30% of the respondents opted for a range of upto 200 kms as seen in Figure 1.3.7.

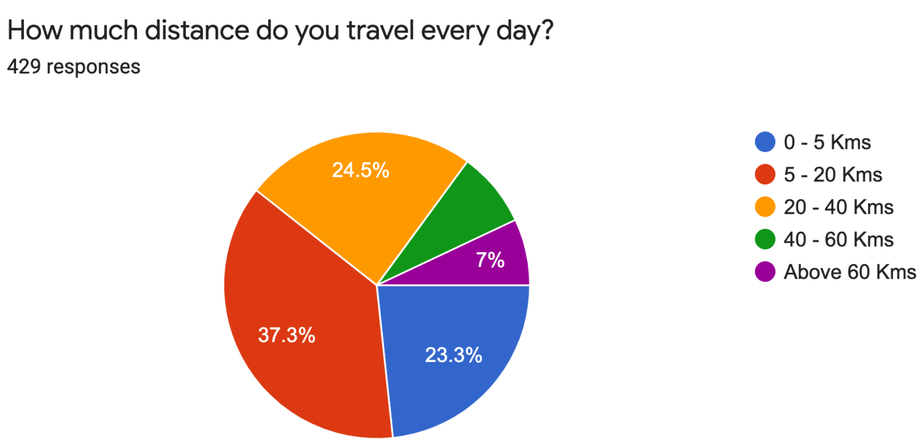


Figure 1.3.5: Survey results - daily commute of respondents

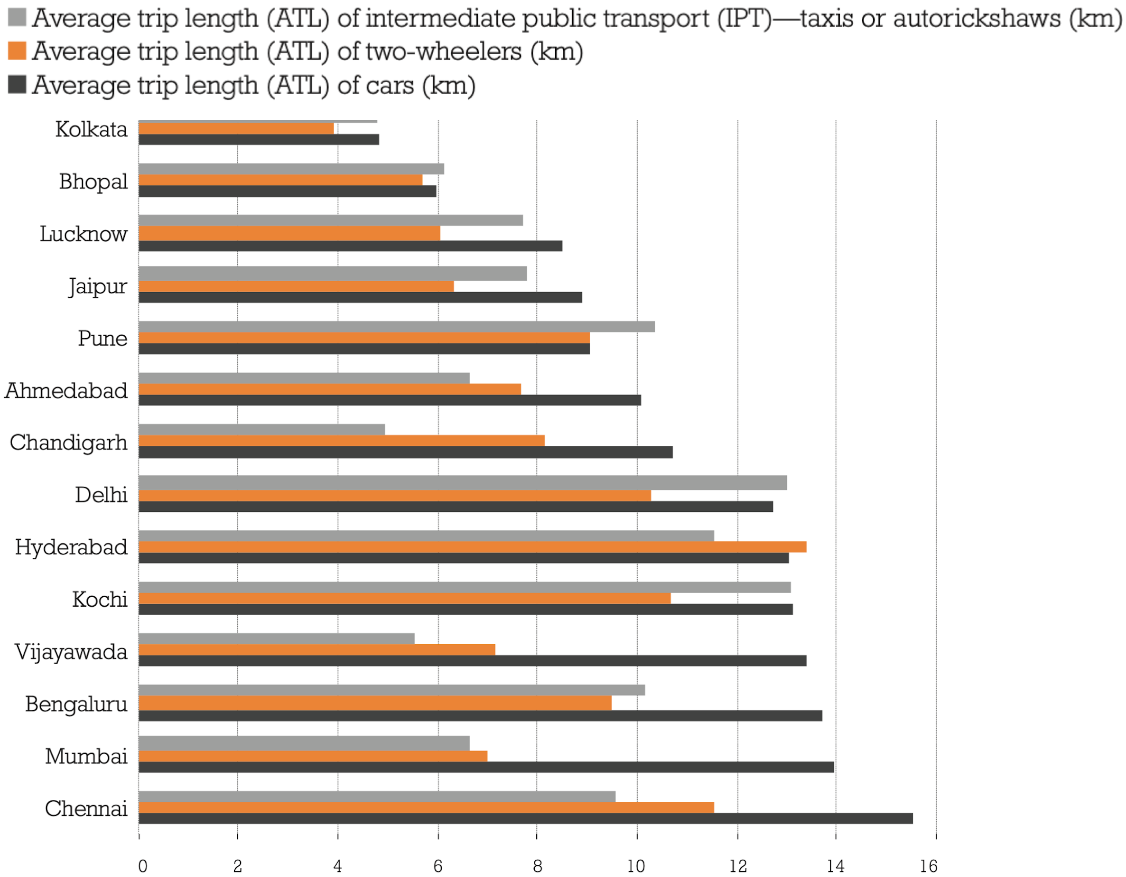


Figure 1.3.6: Average Trip Length of vehicles in 14 Cities in 2017 [12]

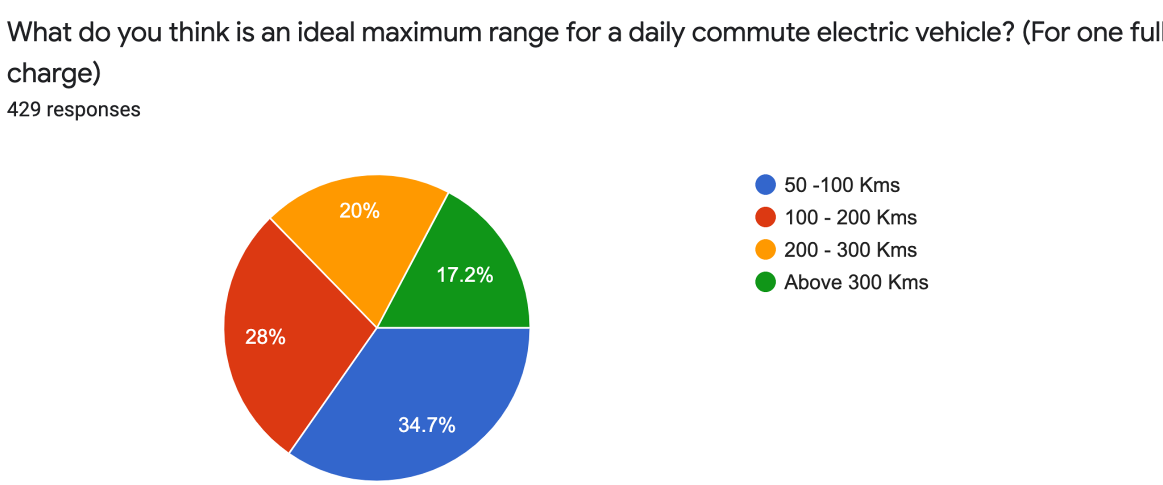


Figure 1.3.7: Survey results - ideal maximum range

Another interesting result of the survey (Figure 1.3.8) is that about 62% of the respondents would buy an electric vehicle for its "Lower emissions". This option to buy an electric vehicle was the most chosen option followed by the option of "Lower vehicle operating costs", which was chosen by just over 50% of the respondents. This could help to conclude that the respondents are aware that there is a prevailing problem with pollution and are willing to be part of the solution for cleaner urban areas more than choosing to keep maintenance and running costs of their vehicle lower than a conventional car.

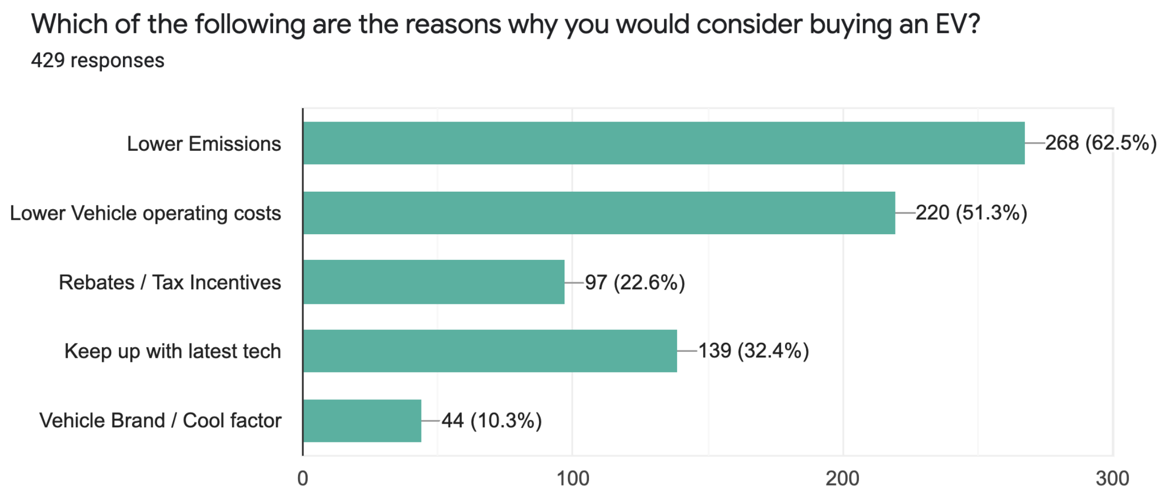


Figure 1.3.8: Survey results - reasons to consider an EV purchase

It is important to note that more than 93% of the respondents are also willing to pay extra if they were to purchase an EV (Figure 1.3.9). This could lead to the conclusion that the supply of EVs is not able to meet the demand in the market and that there is a demand for affordable EVs in the market due to customer awareness of the benefits of EVs. The survey also points out that the respondents would be willing to pay upto €2.300 more for an electric variant of a vehicle than a gasoline variant of the same vehicle (Figure 1.3.10).

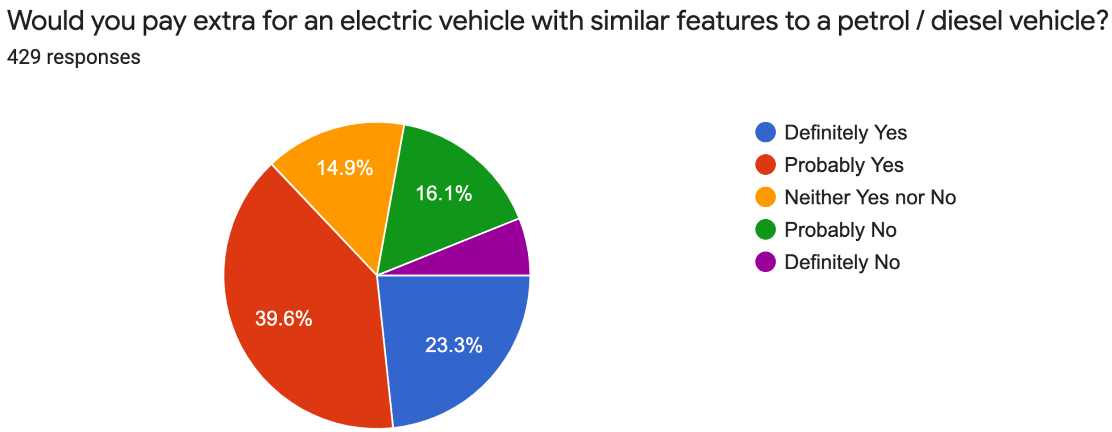


Figure 1.3.9: Survey results - higher price for EV acceptable?

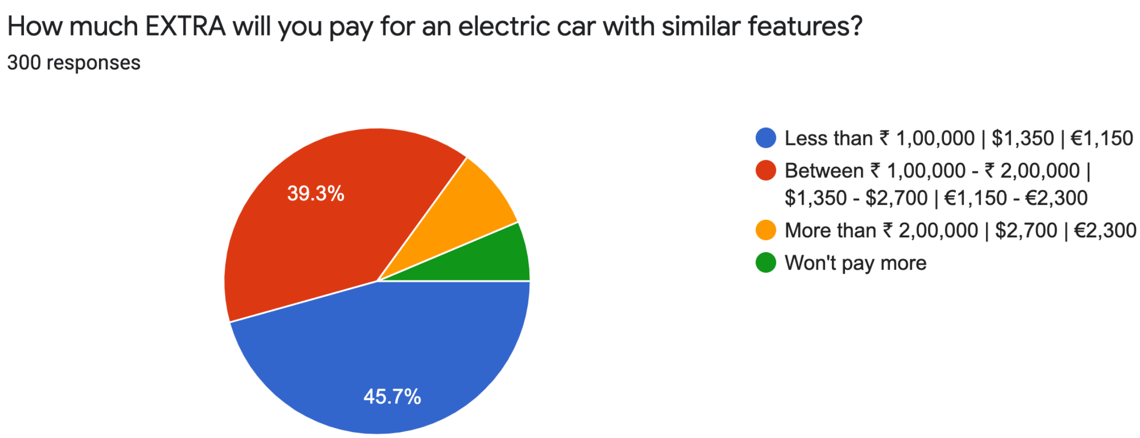


Figure 1.3.10: Survey results - extra pay for EV

The survey results are an indicator for a growing demand and awareness for affordable EVs in India. With government support and favourable regulations for EVs in the market (as mentioned in the previous paragraphs), it is the best time to invest in a new affordable urban mobility solution.

Quadricycles in the Indian market

Since quadricycles are a new category in India, the number of quadricycles in the market is very less; this can also be considered as a favourable scenario for the new proposed quadricycle. The Indian market has the following quadricycles shown below:

Bajaj Qute (LPG / Gasoline) - 4 Seater

Mahindra Reva E20 Plus

Strom R3

Power	19kW
Battery	10.08kWh, Li-Ion, 48v
Weight	932 kg
Range	Up to 110 kms
Price	**8.340€ - 9.204€**

Power	15kW
Battery	Li-ion
Weight	550 kg
Range	Up to 200 km
Price	**From 5.200€**

Table 1.3.1: Specifications of quadricycles in Indian market

Made by Bajaj (the 3rd largest motorcycle manufacturer in the world) the Qute is the first quadricycle in India. It is also the first 4-wheeler designed for first and last mile transportation. Hence, it is lightweight, has a small footprint making it fuel efficient and easy to drive even on congested roads. Qute has got the ARAI approval after meeting the Indian Quadricycle norms and the European WVTA (Whole Vehicle Type Approval) certification awarded by RDW Netherlands [27]. The Qute costs about €3.500 in the Indian market and is aimed to replace three-wheelers (mostly taxis) with increasing safety and emission regulations, but the vehicle is still powered by a gasoline engine.

The Mahindra $E_2$0 Plus, manufactured by Mahindra & Mahindra, is a personal electric city car with a capacity of four people. Even though the $E_2$0 plus is not classified as a quadricycle, the car is very small and is a competitor to the proposed quadricycle. The vehicle has a lot of features like connected car tech, regenerative braking, touch-screen media system which were very attractive options during its launch in March 2013. Even though the car was launched at a price of about €9.000 initially, the automaker later introduced a plan to split the acquisition cost of the car and battery into separate payments and the price of the car was reduced to €6.300 and a monthly lease for the battery at about €30.

The Strom R3 is a new offering in the market and the latest entrant into the quadricycle segment. With prices starting from €5.200, this product has already sold 166 units in the first 4 days after opening bookings [28]. The product is a three-wheeler with an estimated maximum range of 200 kms for a full charge and can carry two occupants with their luggage.

All three of the offerings appeal to three different demographics of the population. The Bajaj Qute appeals more to customers with commercial purposes like city taxis. The $E_2$0 appeals to a type of customer who is looking for a family car that can carry four people. The Strom R3 appeals more to office commuters and two-wheeler owners looking for an alternative mode of transport. The quadricycle market is growing, with more products and innovation this segment will see the fastest growth in terms of sales number in the near future.

1.4. EV sales in Global and Indian markets

Electric vehicles have become popular around the world since the introduction of the Tesla Model S and the subsequent Model X and Model 3, all of which made the EV more appealing and desirable for more people. This is more evident with the EV sales figures in the USA and China, both of which are important markets for Tesla. Figure 1.4.1 shows the global electric vehicle stock (BEVs and PHEVs) from 2010 to 2020 for both two-wheelers and four-wheelers.

All major manufacturers are introducing or planning to introduce more EVs of one or more types in their model line up in all of their major markets including in India, with particular focus on BEVs. The other types of EVs are - HEV (Hybrid Electric Vehicle), PHEV (Plug-in Hybrid Electric Vehicle) and FCEV (Fuel Cell Electric Vehicle). FCEVs are in the very initial stages of development and are being produced by only a few manufacturers; the market for FCEVs is not expected to grow as fast as BEVs for passenger vehicles.

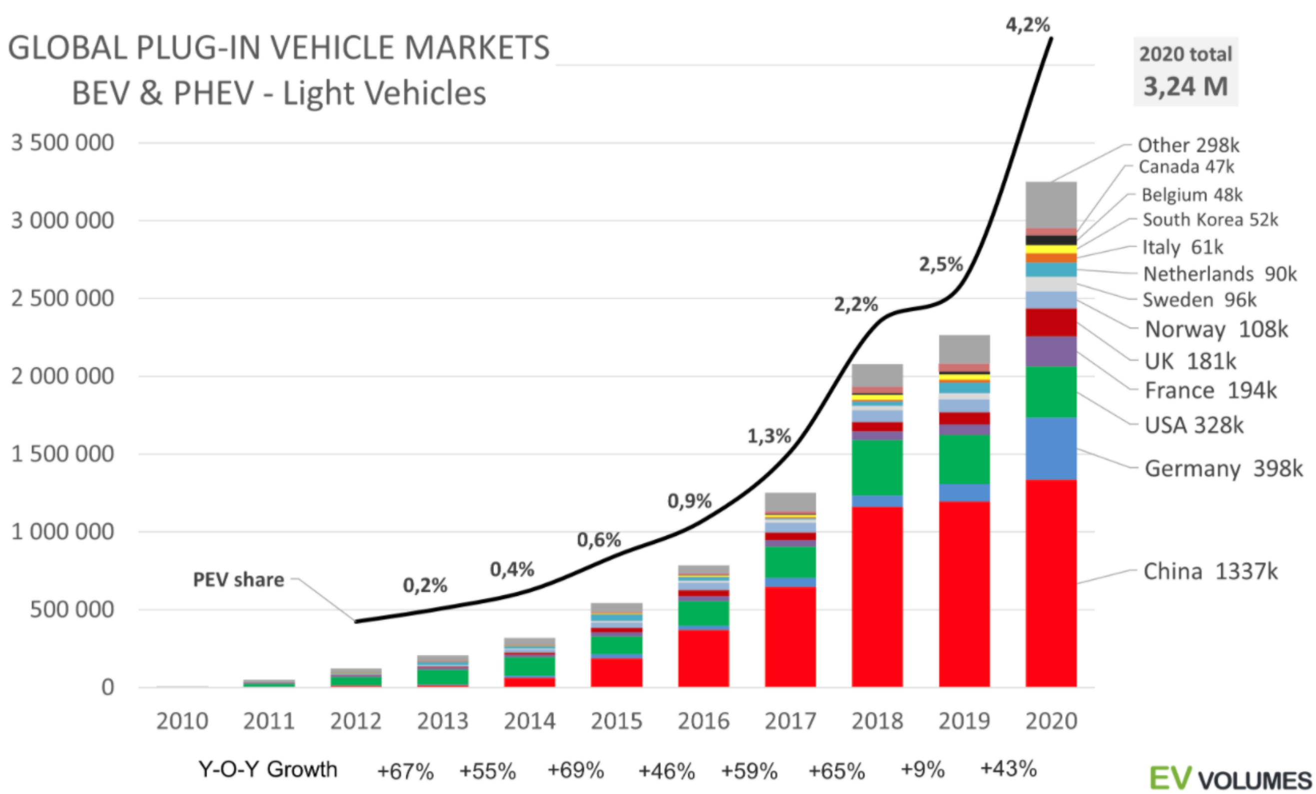
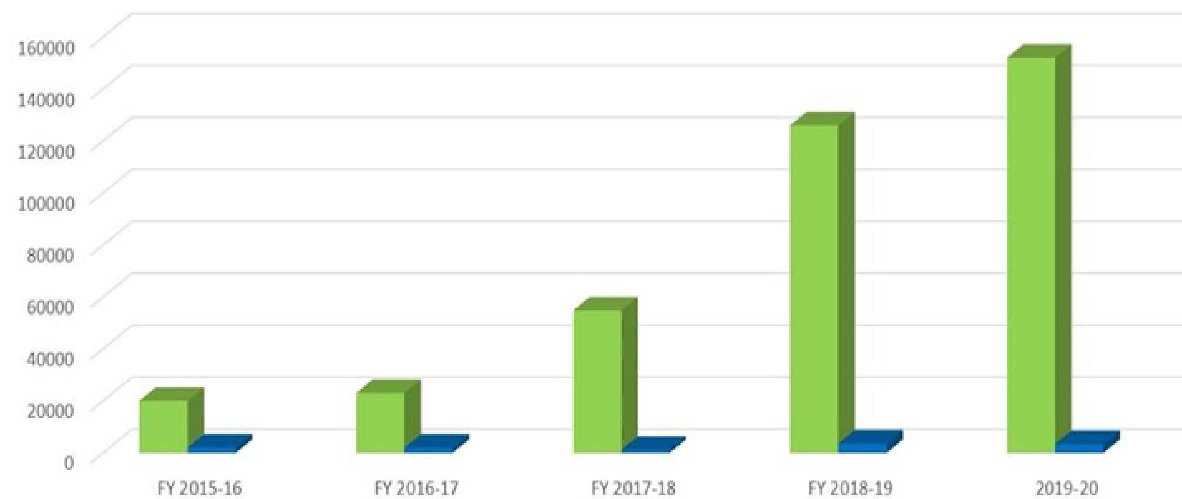


Figure 1.4.1 [29]

Compared to China, the per capita EV numbers are much lower in India, but India is in the beginning of an EV evolution with sales increasing at a good rate since 2018 as per the statistics provided by the Society of Manufacturers of Electric Vehicles (SMEV) [30] seen in Figure 1.4.1. The statistics by the Society of Manufacturers of Electric Vehicles suggest that the sales figures of EVs in 2019-2020 are very similar to some European countries, the majority of EV sales in India are two-wheelers rather than four-wheelers. Infact, manufacturers sold only 3.400 four-wheeler electric vehicles in India in 2020, which is only 2% of the total electric vehicle sales.



E2W	20000	23000	54800	126000	152000
E4W	2000	2000	1200	3600	3400
Total EVs	22000	25000	56000	129600	155400

Source:
Society of Manufacturers of Electric Vehicles

Figure 1.4.2: Electric vehicle sales in India [30]

Global market for electric vehicles

According to a report by IEA (International Energy Agency) the EV sales exceeded the market expectations for 2020. The higher sales numbers were mainly due to existing policy support and new stimulus measures. According to preliminary estimates, the world EV sales increased to 3 million vehicles per year and reached a market share value of over 4% making 2020 a record breaking year for electric mobility. [31]

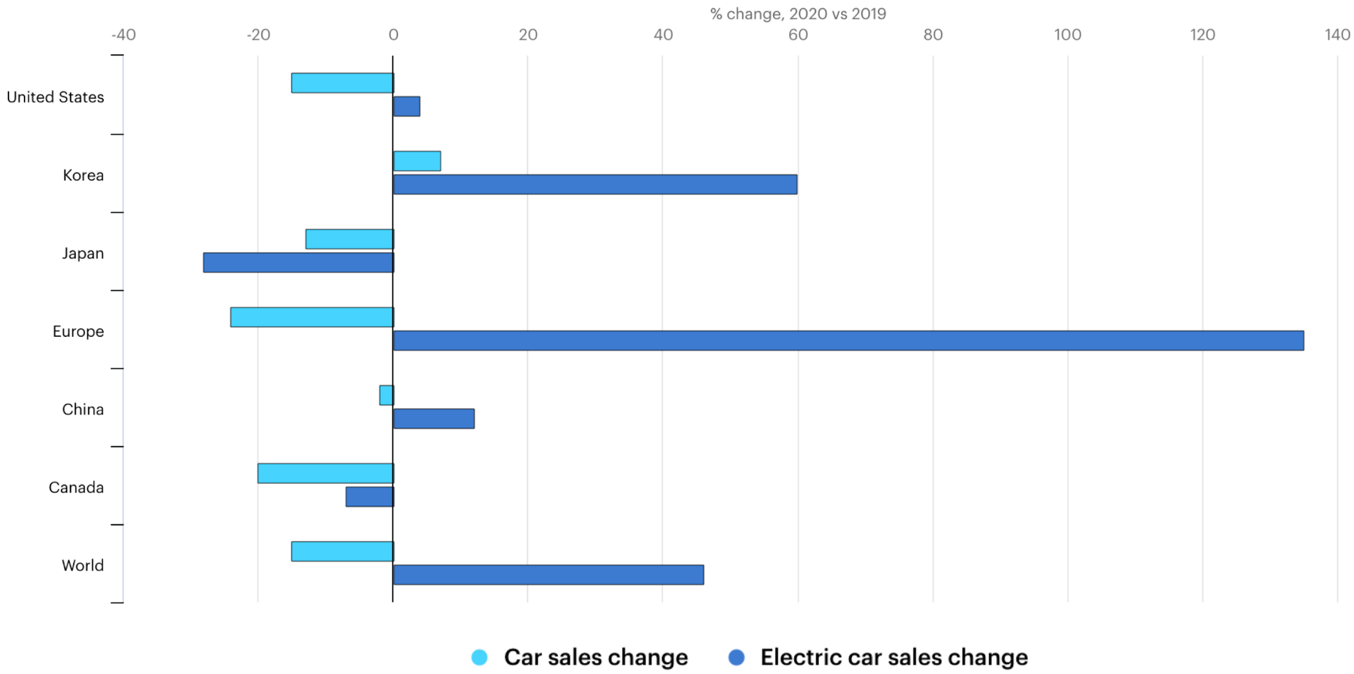


Figure 1.4.3: Percentage change in total car sales and electric car sales [31]

Despite the initial slowdown in vehicle sales from February to May of 2020 due to COVID19 pandemic, electric car sales have been resilient to decreasing sales in Q1 and Q2 of 2020 and have shown a significant increase in overall sales compared to 2019 (Figure 1.4.3) and previous years. The main reasons for this increase in EV sales compared to total car sales are policy support by the government, especially in Europe due to changing emission norms, and decreasing battery costs that lead to better offerings from OEMs. [31]

In 2020, the EV sales in Europe more than doubled over 2019 sales numbers with the major markets like France, Italy, Germany and the United Kingdom having significantly higher sales numbers through each month of 2020 than in each month of 2019. In China, EV sales have a year on year growth of 12% to give a combined sales figure of about 1,3 million electric cars in 2020. In the USA, even without EV stimulus measures at the federal level, EV sales were 4% higher than in 2019 in a car market that shrank by 15%. These aforementioned sales numbers suggest a shift in consumer behaviour towards EVs. [31]

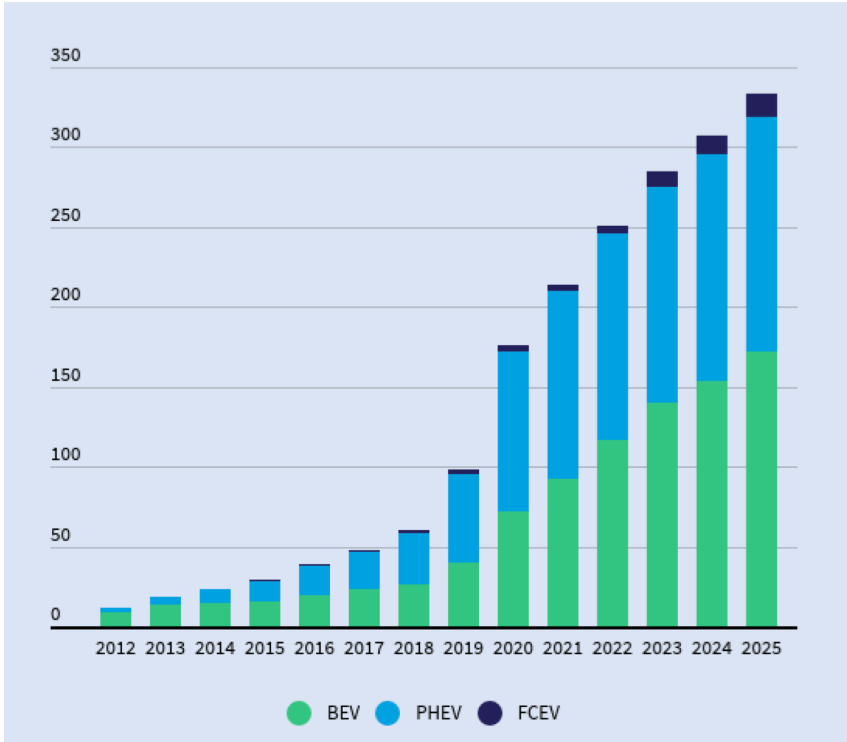


Figure 1.4.4: Total number of EV models in European market with projections [32]

According to a report by European Federation for Transport and Environment [32], the projections for the number of EV models (including BEVs, PHEVs and FCEVs) in the European market are supposed to increase from approximately 200 in 2021 to over 325 in 2025; which is an increase of over 60% in a period of just 4 years (Figure 1.4.4). This report can be taken as a reference to understand an approximate number of new models of EVs to be introduced in other markets worldwide.

The introduction of new EV models by various manufacturers is a clear indicator of the demand that is prevalent in the current market and in the years to come. This push towards EVs is also a result of very demanding emission regulations proposed by world governments, and in order to meet these strict emission levels, manufacturers are adopting electric motors and batteries, sometimes in combination with internal combustion engines to lower the tank-to-wheel emissions.

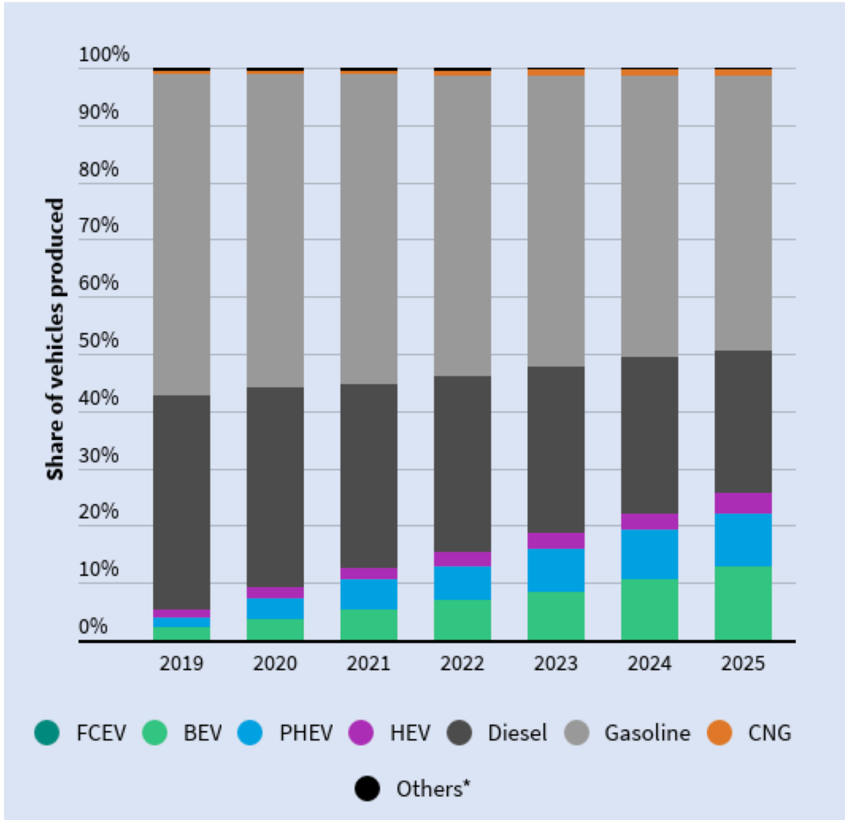


Figure 1.4.5: EU production of vehicles per type in 2025, in share of total production [32]

And the market projections estimate that this increase in market share of EVs will be followed by a significant decrease in the market share of diesel vehicles than gasoline vehicles, especially in the light passenger vehicle market. The new EVs are more efficient, more economical and less polluting; and with a lot of government policies worldwide supporting incentives and tax rebates for EV customers, EVs are becoming the best choice of transportation for the masses.

Figure 1.4.6 shows the projections for the number of EV models by various manufacturers to be introduced in the European market from 2019 to 2025. These projections can be used to predict the number of EV models in various markets worldwide. With the data provided about the European EV market, one could say that the global EV market is resilient to the current pandemic situation and is projected to exceed sales expectations with decreasing battery costs and increasing investments in EVs by manufacturers.

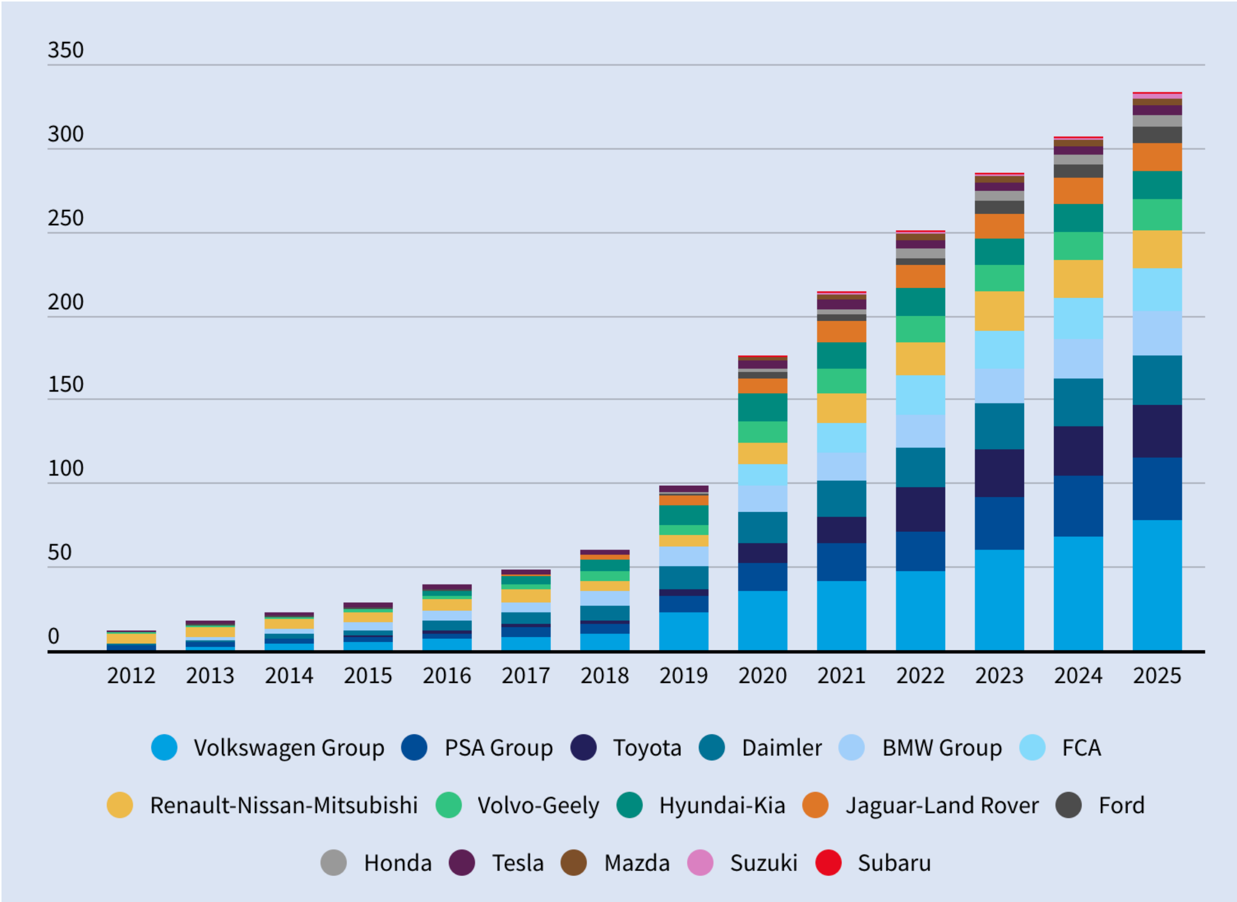


Figure 1.4.6: Electric car models coming to market in Europe 2019 - 2025 [32]

Indian market for electric vehicles

The Indian EV market, like the Chinese EV market, has the majority of EV sales from two-wheelers. But the number of EV sales in the Indian market is not comparable to the Chinese market, as India sold around 155.000 EVs and China sold around 1.337.000 EVs in 2020. India is clearly in the beginning stages of an EV evolution, with sales increasing rapidly. The Society of Manufacturers of Electric Vehicles (SMEV) statistics, the existing government policies and increasing fuel prices (an average increase of more than 40% across India from 2011 to 2021 [33]) in India clearly suggests an increase in adoption of EVs, especially compact EVs in the coming years.

However, shifting to an electric mobility future is not without a few barriers - high upfront costs, EV charging infrastructure, and range anxiety to name a few. At present EVs in the country are more expensive than internal combustion engine (ICE) vehicles purely based on purchase cost. 2019 was the worst time for India's auto industry marked by declining sales and rising inventories, which was then followed up with COVID-19 related slowdown, creating further disruption to the auto industry including auto financing and low demand in the short term. For example, the Indian passenger vehicle sales decreased by 18% in 2019 - 2020 to 2,78 million compared to 2018 - 2019. [20]

The decline in sales is the result of several factors, including the liquidity crisis impacting non-banking financial companies (NBFCs), which account for a third of all automobile loans, and the consequent effect on their ability to accept new loan applications at the same scale as in previous years. In the face of high upfront costs, and the situation among financial institutions to extend loans for EVs, the market demand outlook for EVs continues to be small and far short of the 2030 vision identified by NITI Aayog. [20][19]

However, the response from the market is not in line with the above argument about the future EV sales projections (Figure 1.4.4) as EV sales are increasing at a good rate. Based on the automobile sales projections by Government of India till 2030 in Figure 1.4.7, calculating the number of EVs across segments as per the NITI Aayog vision for 2030 [20] is done by considering 70% of all commercial cars, 30% of private cars, 40% of all buses, and 80% of two-wheelers and three-wheelers to be EVs. EV sales with the aforementioned scenario are taken as the base case.

However, since EV adoption requires a higher initial investment with a long familiarisation and adoption period of two to five years and accounting for behavioural changes by the adopters, their adoption is considered as a process rather than an event. Trade-offs and technological advances around charging infrastructure, the total cost of ownership over the lifetime of the vehicle across different use cases, and declining battery costs are all continuously evolving, which makes this a very dynamic market. Policy support and regulatory interventions by the government, like emission standards and tax rebates have proven to be important levers for giving EV an edge over the competition.

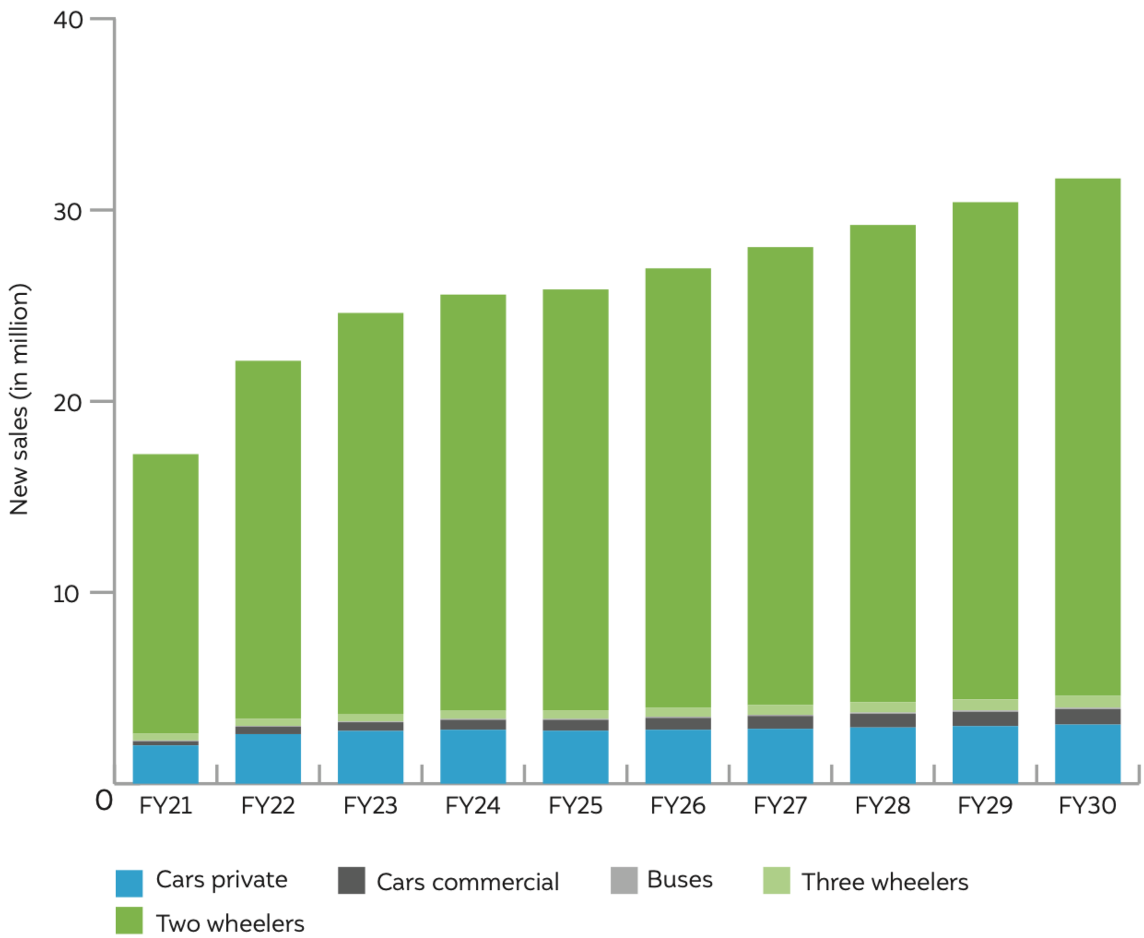


Figure 1.4.7: Indian market vehicle market total sales projections 2021 -2030 [20]

According to the report by Center for Energy Finance [20], that was referred to previously, to reduce the unpredictability and uncertainty around the transition towards these projections in the NITI Aayog report, vehicle sales are split into the aforementioned base case and three other scenarios – the high, medium, and low adoption scenarios (Figure 1.4.8).

The level of EV adoption in the aforementioned scenarios is most likely to be driven by three factors - regulatory changes favouring EVs at both the demand and supply side, namely restrictions on conventional vehicles; market pull towards EVs based on the favourable ownership costs of EV compared to ICE vehicles; and infrastructure support from the government for setting up EV chargers. [20]

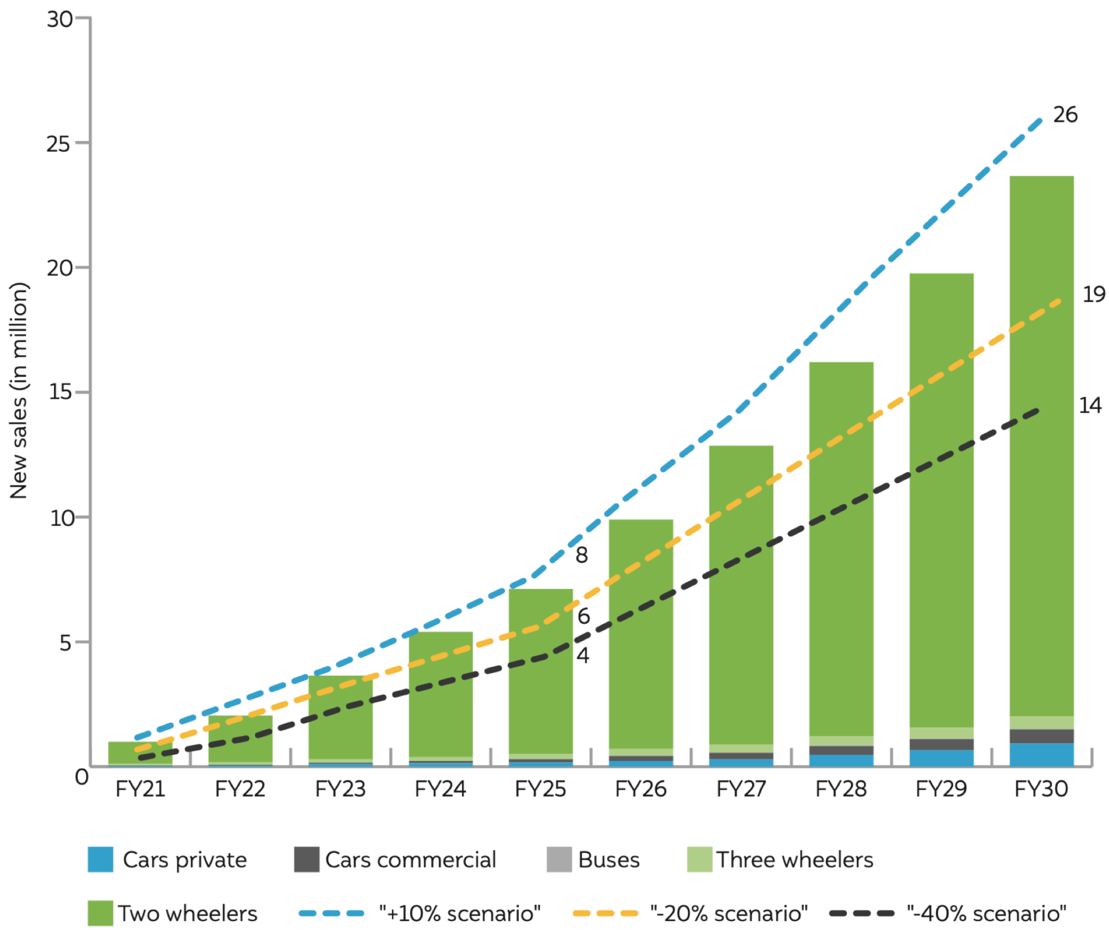


Figure 1.4.8: Indian market EV sales projections with scenarios 2021 -2030 [20]

Various scenarios under consideration:

High adoption scenario:	Projected sales 10% above base case
Medium adoption scenario:	Projected sales 20% below base case
Low adoption scenario:	Projected sales 40% below base case

By 2030, EV sales are expected to overtake IC Engine Sales. From Figure 1.4.8, in the base case, the cumulative EV sales in all vehicle segments are estimated to be 102 million units by FY30; this could go up to 112 million units in the high adoption scenario, 81 million units under the medium adoption scenario, and 61 million units in the low adoption scenario [20].

According to the report by Center for Energy Finance [20], India plans to bring several amendments and new policies to boost EV and EV component manufacturing locally; although this will slow down any decrease in the costs of EVs, thus delaying their adoption, it will allow India to capture the benefits of the transition in the form of jobs and economic value, and is therefore likely to be followed by strong, demand-boosting measures. These constraints make both the low and medium adoption scenarios, which project EV sales to be 40 and 20 per cent below the stated NITI Aayog target for 2030 respectively in Table 1.4.1, more possible scenarios towards higher EV adoption in the country.

In the base case, the cumulative EV sales in all vehicle segments is estimated to be 102 million units by 2030; this could go up to 112 million units in the high adoption scenario, 81 million units under the medium adoption scenario, and 61 million units in the low adoption scenario. Of the total new vehicle sales, EVs account for as much as 43 per cent of the share in the high adoption scenario and as less as 23 per cent in the low adoption scenario. [20]

SNo.	EV Sales FY21 to FY30	Base Case	High Adoption	Medium Adoption	Low Adoption
1	Two-wheelers	94	103	75	56
2	Three-wheelers	3	3	2	2
3	Cars (Private)	3	3	2	2
4	Cars (Commercial)	2	2	2	1
	Total	**102**	**112**	**81**	**61**

Table 1.4.1: Projected EV Sales numbers from 2030 for various scenarios [20]

1.5. An overview of the battery market in India

The increase in EV sales will create an unprecedented demand for batteries and related raw materials worldwide. The need for batteries will be driven by both new sales of EVs and the increasing demand for replacement batteries in existing EVs.

Investments for battery industry

According to a study by the New Delhi Council for Energy, Environment and Water [20], the demand for new and replacement batteries were estimated based on vehicle sales, battery capacity, and the battery life of each vehicle segment.

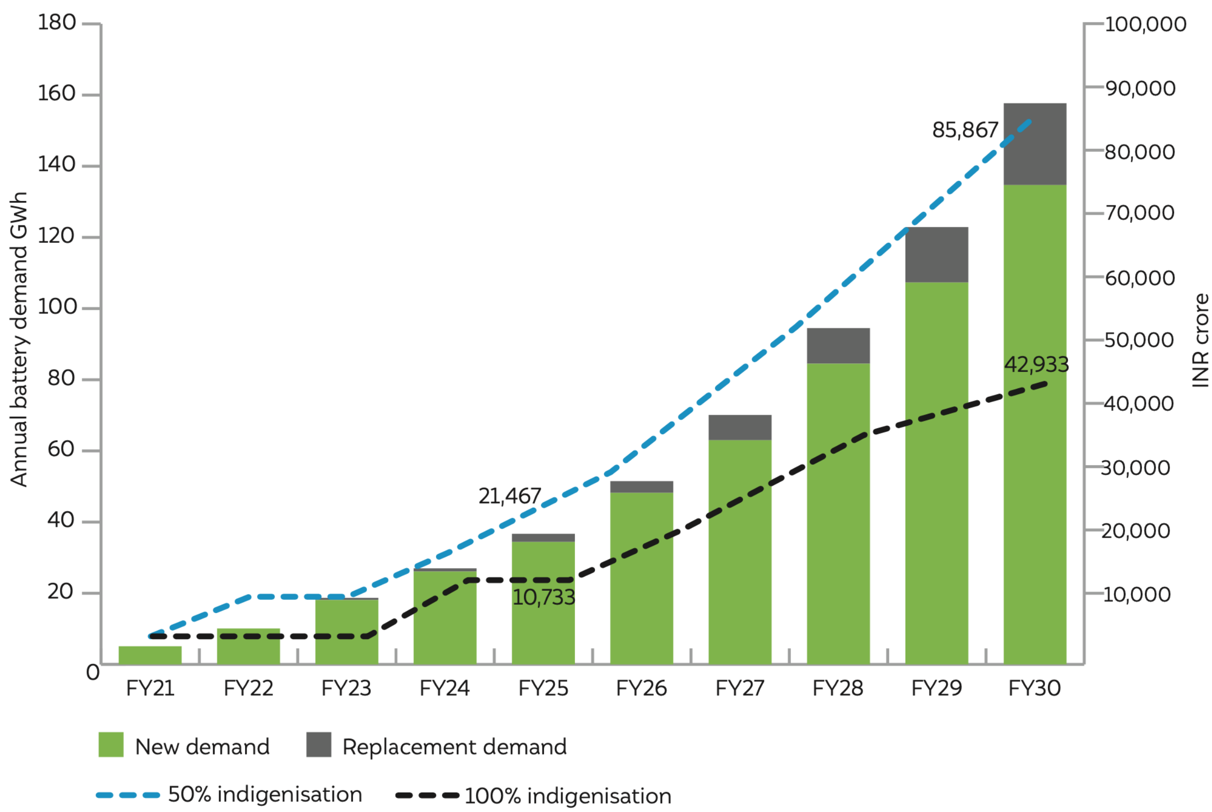


Figure 1.5.1: Battery capacity demand vs market capital for India [20]
(1 crore = 10 million)

The CAPEX (Capital Expenditure) for setting up a 10 GWh production capacity plant was assumed as $730 million based on secondary research of a recent battery manufacturing collaboration between General Motors and LG Chem. Based on the projected demand, the annual investment required for a battery manufacturing facility was calculated for the 100 per cent and 50 per cent indigenisation scenarios in the study.

According to the study, to meet this potential demand, battery manufacturers will need to expand their production capacity substantially. This vast expansion will require huge investments, which will vary according to the level of battery manufacturing indigenisation. Under a 50 per cent indigenisation of battery capacity scenario, investments incurred by FY30 will stand at about $6,1 billion. The cumulative investment required would top $12,3 billion in case of 100 per cent indigenisation of battery manufacturing.

The investment requirement for battery manufacturing is proportional to the increase in EV adoption. According to Figure 1.5.1, in the high adoption scenario (+10 percent scenario), the battery manufacturing investment requirement can rise to $1,31 billion. In the low adoption trajectory (-40 percent scenario), it could be down to $730 million. [20]

Battery market demand estimation

To estimate the demand for battery packs, the study [20] considered both new vehicle sales projections and the demand projections for replacement batteries (as the life of a vehicle usually exceeds the life of any battery pack). Different capacities of batteries were considered for different types of vehicles. For example, the battery capacity required for an electric two-wheeler is in the 3kW range, while that required for an electric bus is in the 200 to 320kW range. The new demand for batteries is estimated in GWh using the battery capacity requirements for each vehicle segment and its respective sales. Then, the replacement battery demand is calculated based on battery life, the average life of the vehicle, and the average distance covered. The demand for battery replacements may initially be zero, but it will later increase depending on the vehicle's age. Thus, the total battery demand grows at a faster pace than the vehicle stock.

Based on this method, projections shown in Figure 1.5.2 indicate a significant rise in annual battery demand from 5GWh in FY21 to 158GWh by FY30. By FY30, the battery replacement market is likely to contribute about 11 per cent of total EV related battery demand. In comparison, new batteries will contribute about 89 per cent of the total battery demand.

Across all vehicle segments, electric cars for commercial use are likely to be the main driver for the demand for replacement batteries, accounting for 58 per cent of the total replacement demand. Also, electric private cars and buses are likely to account for 14 per cent and 19 per cent, respectively, of the replacement demand during this period. The replacement demand for buses is higher because of the higher average annual vehicle kilometres covered as opposed to other vehicle segments, which travel fewer vehicle kilometres during their lifetime. [20]

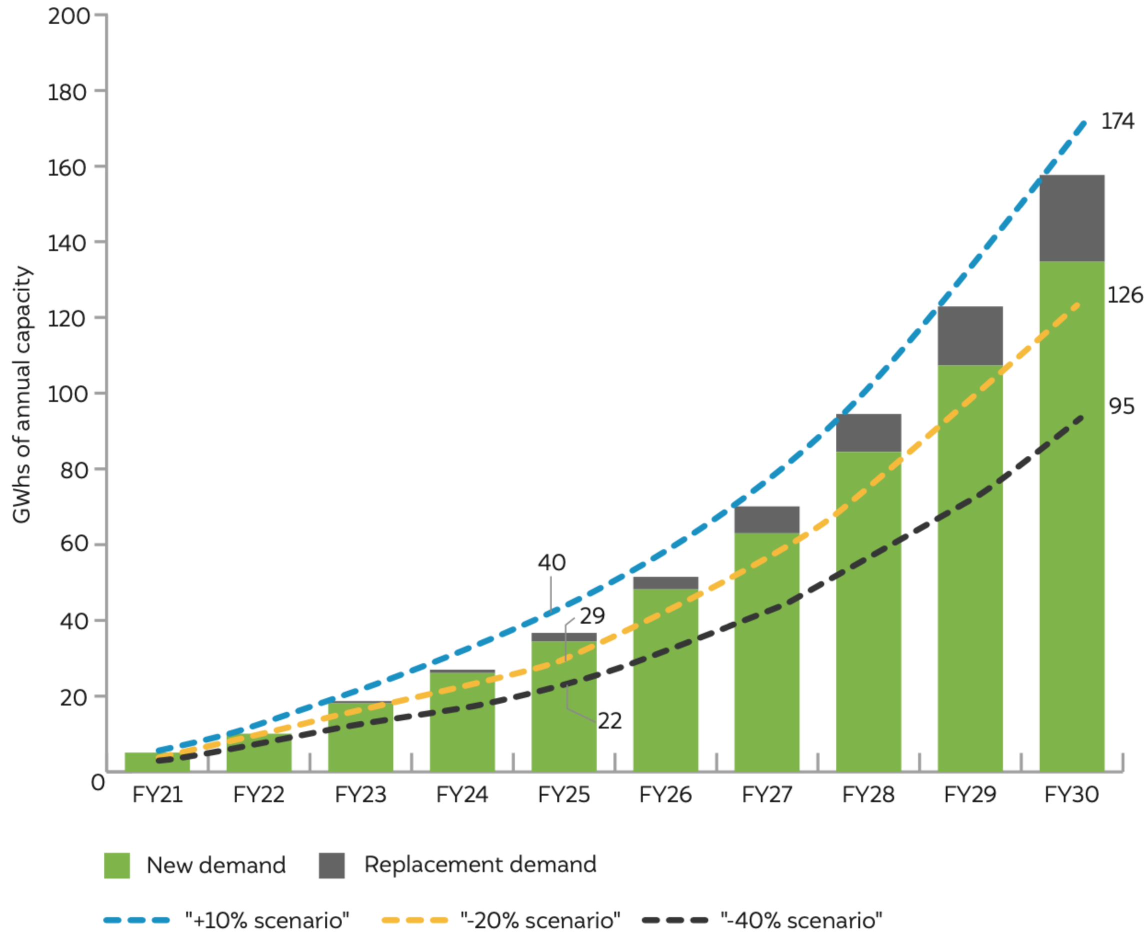


Figure 1.5.2: Battery demand for EVs under various scenarios [20]

1.6. Challenges for electric vehicles in India

The EV market is projected to increase and India is projected to be an important global player for EV manufacturing and sales as it is now with ICE vehicles. However, this shift to new technology comes with a few hurdles to overcome as it is the case with wider adoption of any new technology. Some of the challenges that are faced or will be faced by the India EV market are as follows:

Electrification in India

India's electric-vehicle market has only just taken off in terms of sales numbers, and is miniscule compared to China, Europe, and US markets (refer to Figure 1.4.1 and Figure 1.4.2) . According to a research paper [18], despite the prevalent push for vehicle electrification by policymakers, the projected load added to the power infrastructure for BEV charging by 2030 is less than 3% of the total electricity load in India.

This low energy demand for EVs is suggested because of the following three possible scenarios:

1. In most urban areas of India, the rapid increase in electricity demand from numerous other end-uses (particularly air conditioners) will be very large over the next 15-20 years, thus dwarfing the percentage of electricity consumption by EVs.

2. The vehicle penetration by 2030, according to projections, is dominated by 2-wheelers that require much less energy than cars and have lower battery capacities. Hence, less total energy used.

3. The overall vehicle penetration is expected to be significantly lower than the other industrialized or emerging economies like China, USA and Europe that are significantly ahead in terms of sales of high capacity EVs.

If managed correctly and planned for proactively, this new large and flexible load (in time and location) will support revenue growth and improve the efficiency of DISCOM operations. However, if new demand is not met proactively, DISCOMs will be challenged by large numbers of interconnect requests and little control of the new load. This will result in a lost demand side management opportunity and a slowing of demand growth.

DISCOMs need to start planning today for the expected demand growth in the coming years and decades. The first step in planning for an EV future is to build capacity across the key stakeholders to ensure all parties have the fundamental knowledge required to have productive planning discussions. [34]

As the advantages and disadvantages of electrification continue to evolve in years, reduction in emissions and lower dependency on oil imports are clear advantages of electrification. The level of adoption of electric vehicles will determine its impact on the automobile industry. According to industry experts, people carriers like buses, two and three-wheelers, luxury passenger vehicles, and light commercial vehicles could see maximum penetration by 2030. This will be followed by other passenger vehicles, medium and heavy-commercial vehicles, and construction equipment, which will take longer for EVs to penetrate. [18]

EV charging network and infrastructure

Electric Vehicle Supply Equipment (EVSE) or EV charging equipment are a prerequisite for EV adoption by prospective customers. Various countries adopt different approaches and business models for creation of the EVSE ecosystem with mixed results. As India is gearing up for an EV revolution, more investments by multinational companies are happening in the EVSE sector.

Most vehicles are equipped with an on-board charging system that converts existing grid-supplied AC power to DC power which is thereby used to charge the battery. Onboard chargers enable a vehicle to be charged directly from a standard home plug (slow AC) or from a specialized AC charger (moderate AC) at home, workplace, or public location. Chargers that provide direct current to the vehicle battery and bypass the onboard converter are referred to as DC chargers or DC fast chargers due to their ability to provide higher charging rates.

DC fast charging stations serve significantly higher number of customers per day and have much higher peak power demands. While most Indian made electric vehicles today cannot accept 50kW fast charging today, it has been established as the standard fast charging power in the global EV market and it is expected that many vehicles operating in India will charge at 50 kW and higher in the future. [34]

The existing public EV charging infrastructure in India is not capable of sustaining rapid growth in EV sales, however the market study points to the fact that early adopters of a technology are almost always willing to overlook certain disadvantages of a product/solution. At present, most EV customers use private home chargers (220V 15 Amps, AC output - 3,3 kW for the Indian electrical network), since public charging infrastructure is scarce. It is important to note that private vehicle charging is very slow; but during long distance travels or when electric taxis or electric buses need charging, a fast charger (>20 kW output) is always preferable.

As a part of the larger EV adoption push, different aspects of EVSE deployment—standards, incentives, adoption and execution—have been entrusted to different government entities. The following Table 1.6.1 lists out the entities and the roles and responsibilities:

Organisation	**Details**
Department of Heavy Industries (DHI)	Overseeing the second phase of Faster Adoption and Manufacturing of hybrid & Electric vehicles (FAME II) in India.
	Circulated an expression of interest inviting proposals for availing incentives under FAME II for deployment of EV charging infrastructure.
Ministry of Power (MoP)	Issued “Charging Infrastructure for Electric Vehicles—Guidelines and Standards”
	Charging of EVs to be considered a service and not a sale of electricity.
Department of Science and Technology (DST) & Bureau of Indian Standards (BIS)	BIS and DST are working together on indigenous charging standards.
	DST is supporting industry-academia collaborations to develop indigenous low-cost chargers.
Central Electricity Authority (CEA)	CEA is entrusted for the creation and maintenance of a national database of all public charging stations working with both state and national nodal agencies.
Bureau of Energy Efficiency (BEE)	BEE to is the central nodal agency for rollout of EV public charging infrastructure as MoP’s guidelines.
State DISCOMS	State DISCOMS are the default nodal agencies at the state level unless a state government deems in favour of other urban local bodies or public sector units.
GST Council	Tax reduction on charger or charging stations for EVs from 18% to 5% (with effect from 1 August, 2019).
Energy Efficiency Services Limited (EESL)	A JV under MoP, EESL has been actively installing public charging stations in Delhi.

Table 1.6.1: Roles and responsibilities of government entities in setting up EVSEs [34]

The $1.350 million FAME II scheme promoted by the Government of India is a key driver for EV adoption in the country. Also important is the $134 million from the scheme earmarked for development of charging infrastructure. The DHI (Department of Heavy Industries) has been inviting proposals for availing of this incentive for the deployment of EV charging infrastructure across cities in India in August 2019. As of January 2020, 2.636 EV chargers have been allotted the incentive in 24 states and union territories, and out of this 2.636 EV chargers, 1.633 are fast chargers. [34]

317 Maharashtra	205 Rajasthan	131 Kerala	37 Bihar	18 Odisha
266 Andhra Pradesh	172 Karnataka	72 Delhi	29 Sikkim	10 Uttarakhand
256 Tamil Nadu	159 Madhya Pradesh	70 Chandigarh	25 Jammu & Kashmir	10 Puducherry
228 Gujarat	141 West Bengal	50 Haryana	25 Chhattisgarh	10 Himachal Pradesh
207 Uttar Pradesh	138 Telangana	40 Meghalaya	20 Assam	

Table 1.6.2: State wise allocation of EV chargers [34]

Establishing adequate charging infrastructure is key to successfully making the shift to EVs. To increase the adoption of EVs, charging stations will have to be set up across urban areas and highways across the country. However, public charging requirements will vary not just based on EV sales but also the public charging needs of different vehicle segments.

Energy sources in India

The growing population, advances in affordable technology and increase in per capita consumption of electricity has resulted in an almost exponential increase in energy demand across India. This situation is more prevalent in cities than anywhere else, because of a higher population density, due to migration of people from rural areas to urban areas. [13]

Oil, gas and electricity are the major resources to supply the energy needs of the nation. The nation's dependency on oil and gas is a critical issue, so the country is looking forward to various renewable energy resources. To accomplish this target, various government organizations are investing in solar and wind energy-related projects across the country. The study concludes that coal and petroleum product imports are continuously increasing in the country for power generation and increasing the level of greenhouse gases. So, the Indian government is investing in power generation projects based on renewable energies in the country. 'Solar Mission' to achieve a goal of 20.000 MW solar electricity and 60 GW wind power generation by 2022 is in progress. [13]

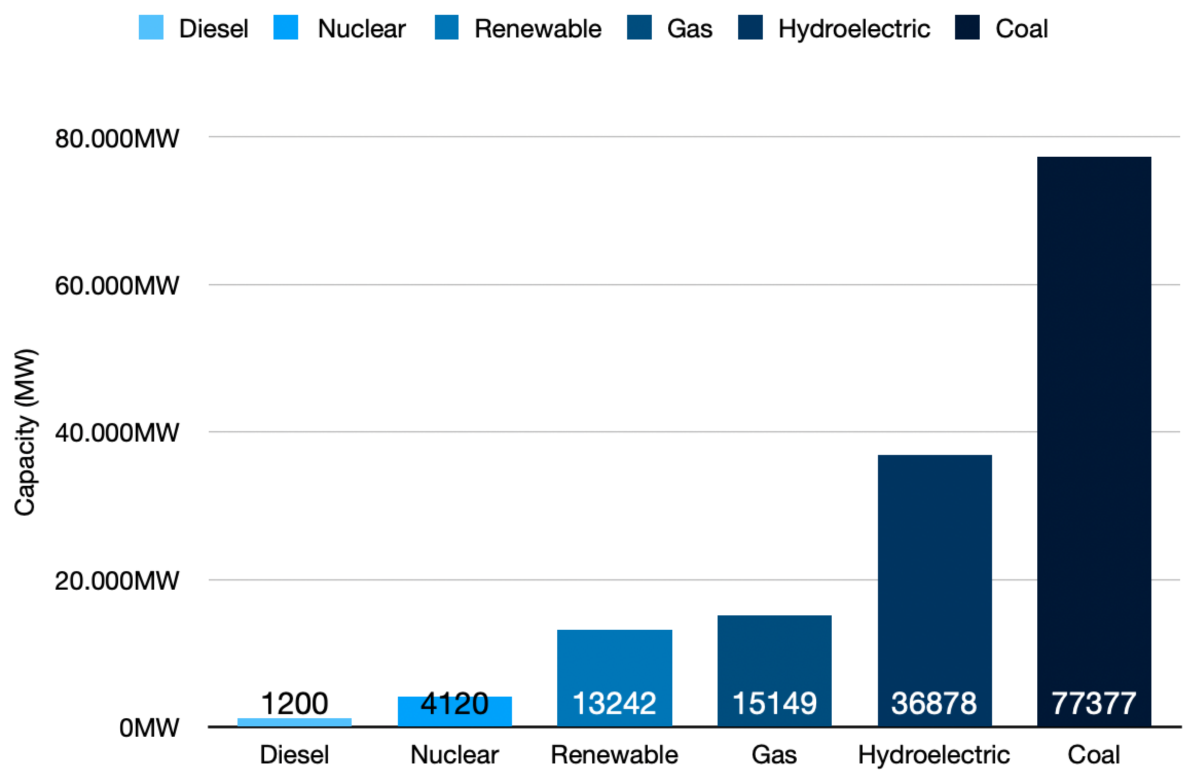


Figure 1.6.1: Capacity of various sources of electricity in 2009 [13]

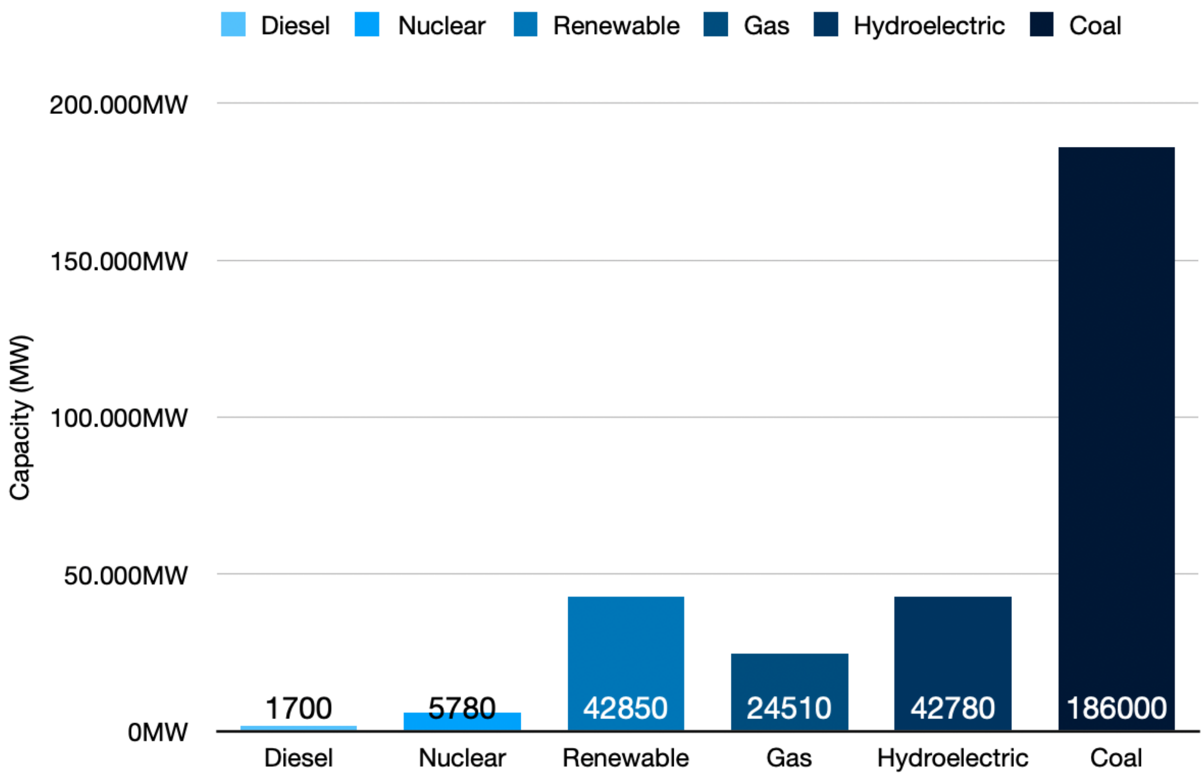


Figure 1.6.2: Total installed capacity of electricity sources in 2016 [13]

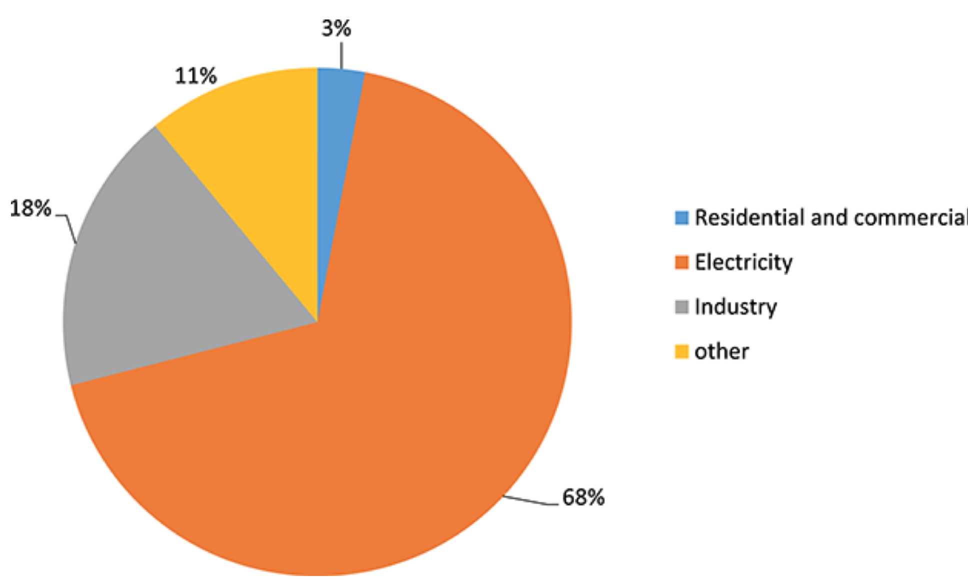


Figure 1.6.3: Sector wise energy consumption in India [13]

According to Figure 1.6.1 and Figure 1.6.2 that show the capacity of various sources of electricity in India in both 2009 and 2016, it can be interpreted that the total capacity has more than doubled from almost 147.000 MW to almost 300.000 MW, but more importantly the capacity of coal powered electricity generation plants have more than doubled and the capacity of renewable energy generation plants have more than tripled. Even though the increase in capacity of coal powered electricity plants is not a favourable scenario because of increasing air pollutants from burning coal, it is important to note that the capacity of renewable energy generation plants has more than tripled. If the government can sustain this rate of growth, the total contribution from renewable energy sources can make a dramatic decrease in air pollution in India by 2030.

Shifting to EVs will enable to have cleaner air in urban areas (air pollution is a major problem in urban India, as discussed before in this thesis), but if India needs to have a true shift in the right direction of tackling air pollution, it will need to focus more on renewable energy sources like solar energy and wind energy. This new focus will enable the nation to have true zero emission from well to wheel rather than zero emission from tank to wheel. Depending on coal to produce electricity that will in turn be used to charge EVs will only shift the pollution sources from urban areas to rural areas, and is not a long term solution.

According to the UN environment program report, India has more investment in the renewable energy sector than any other energy sector. Renewable energy is expected to be responsible for 43% of Indian power generation by 2027. [13]

Battery recycling capabilities

India has recently introduced the Vehicle scrappage policy (discussed previously in this thesis), which has various PPP (Public Private Partnership) entities that monitor the health of vehicles to assess whether a particular vehicle is fit to continue public road usage based on emission results and general vehicle maintenance after 15 years of age. Even though there is no specific rule incorporated to monitor battery health of EVs, the government could integrate new guidelines for EVs in the future as sales of EVs increase in the coming years.

While mentioning battery recycling, it is noteworthy to mention the efforts of a particular German company - Duesenfeld [35]. The Duesenfeld recycling process chain involves mechanical processing and hydrometallurgy (unlike only pyrometallurgical battery recycling in some methods) has been developed with the aim of recycling all materials with high efficiency (upto 91% material recovery) and high quality. Duesenfeld has an unique recycling process, which recovers the metals, electrolyte solvent and graphite separately and makes the Duesenfeld process the most environmentally friendly recycling process for lithium-ion batteries.

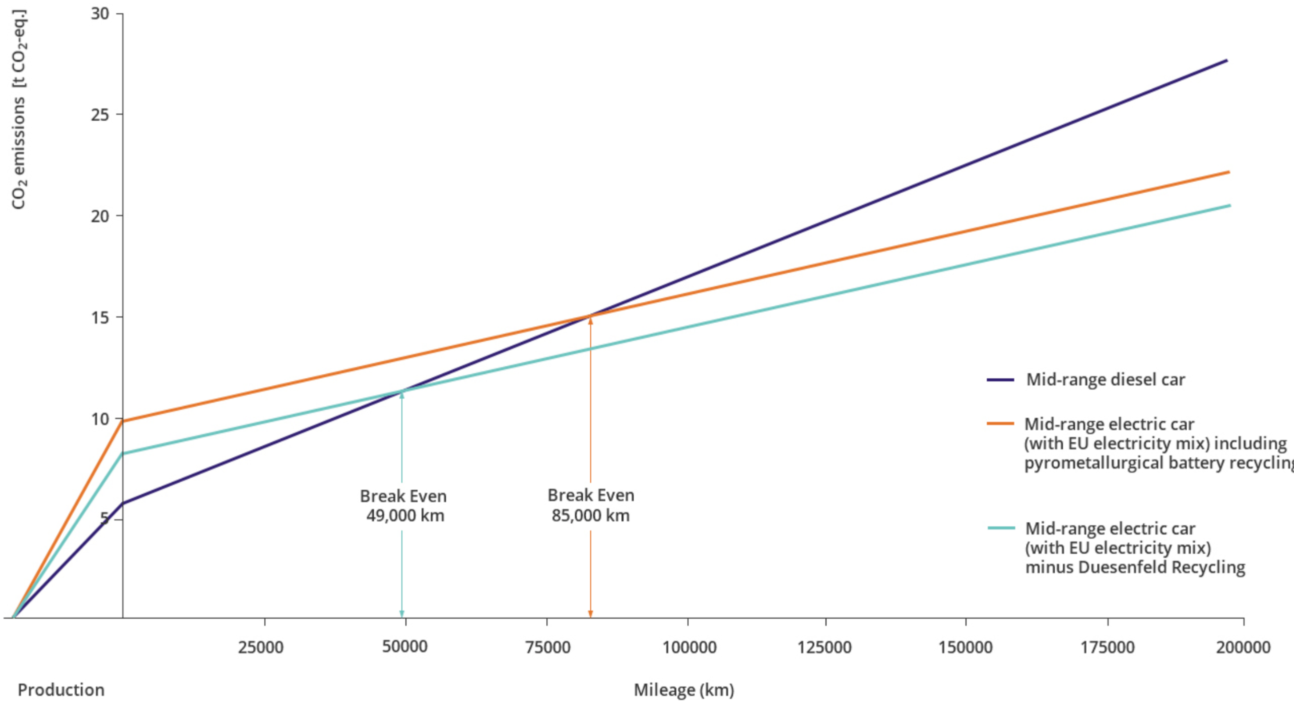


Figure 1.6.4: Impact of battery recycling on total CO_2 vehicle emissions [35]

Within the product life cycle of an EV, a significant proportion of its carbon footprint can be attributed to the production of the battery. For achieving sustainable mobility in EVs, it is very important that the raw materials from used batteries remain within the material cycle to the greatest possible extent and this is made possible by the patented Duesenfeld process. A mid-range electric car equipped with a recycled battery made using the Duesenfeld recycling method achieves a better CO_2 footprint after just 49.000 km, which is much earlier than a similar mid-range electric car equipped with a battery from a conventional recycling process. [35]

These innovations and improvements in battery recycling could be implemented in the Indian market in future for a high recycling efficiency and environmental sustainability.

2. Vehicle architecture

With the increasing pollution levels, traffic congestion and improving adoption of personal vehicles in urban areas, the government would have to plan for a long term solution and a short term solution. While the short term solution would be to change all intra-urban transportation platforms to electric or hybrid solutions to reduce pollution within the urban areas; the long term solution would be to shift to sustainable and environmentally friendly renewable energy generation methods for maintaining overall air quality and general pollution levels. This is because most of the current energy generation is from coal plants outside urban areas as seen in section 1.6. of this thesis. Considering the above mentioned factors about India and the Indian automobile market, an affordable electric vehicle that is comparable to a two-wheeler in dimensions could transform a majority of the downfalls in urban areas

This thesis will explore one possible solution to urban mobility needs in India - an electric L7M Category (Heavy Quadricycle) quadricycle for personal commuting [51]. The reason for choosing a quadricycle has already been discussed in Chapter 1 of this thesis. The vehicle architecture chapter of this thesis aims to explore in detail the various technical, design and practical aspects of a quadricycle that could help to negate the problems caused due to various means of transport and limited transportation infrastructure in urban India by providing a means of personal transportation that is also sustainable.

2.1. Product definition

A personal mobility solution that costs less than an average compact car, that is easy to use in urban traffic conditions like a motorbike while being environmentally friendly and costs less to run and maintain is an advantageous scenario for any vehicle customer. With reducing Li-ion battery costs [55] and new methods of production [88], manufacturing a new personal urban mobility vehicle at an affordable cost and making a profit is a possible scenario. If such a solution were to be produced, the preferred characteristics and design features would be as follows:

Average vehicle occupancy

The average vehicle occupancy of private vehicles in India was recorded at between 1,5 and 2 people per vehicle for four-wheelers and between 1 and 1,2 people per vehicle for two-wheelers according to a study done by the Centre for Science and Environment, New Delhi [12].

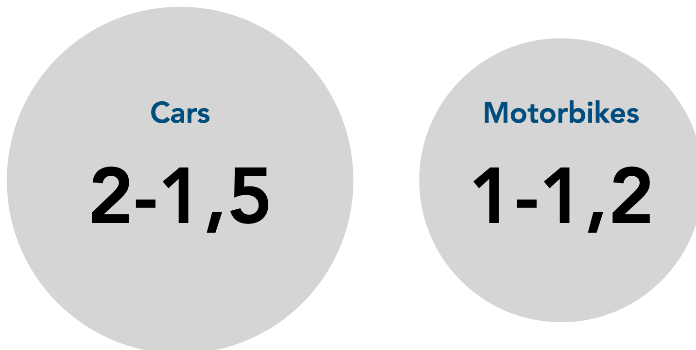


Figure 2.0.1: Average occupancy of private vehicles in India [12]

Vehicle characteristics

One possible solution to personal urban mobility needs in India is an electric L7e Category (Heavy Quadricycle) quadricycle. Such a quadricycle has to be:

- **Small** - to easily manoeuvre in urban traffic
- **Electric** - to reduce emissions inside urban areas
- **Reasonably priced** - for wider adoption
- **Safer** - to reduce road accident fatalities compared to motorcycles
- **Great design** - to have broader appeal and desirability

Also, choosing to produce an electric quadricycle with an **enclosed climate controlled cabin** rather than an open electric scooter will enable the user to have better protection from the weather elements, especially the extreme heat and UV radiation in summer and heavy rains during the monsoon season; which is an impending adverse climate scenario in India and all urban areas in India have one of these situations in common with each other [36]. A representational image for the quadricycle is shown in Figure 2.0.1 to understand the proposal in a better way.

The quadricycle will serve the purpose of intra-urban personal transportation for commuters who are otherwise used to higher segment two-wheelers or lower/mid segment four-wheelers for commuting to and from offices, shops or other routine activities. The vehicle could be the only vehicle for a young driver or it could be a secondary or tertiary vehicle in a family and shall provide a safer and more comfortable transportation solution than a motorcycle, while being smaller and easier to navigate than a four-wheeler.

Product design elements

An ideal design for the personal urban mobility solution would be comfortable like a car with an enclosed climate controlled cabin and would be easy to use and navigate through traffic like a motorbike. The Figures 2.1.2 to 2.1.6 show the representational images [106] for the suggested quadricycle with an enclosed cabin for HVAC, two seats (driver + one passenger behind the driver) and a steering wheel.

Another unique design suggestion for a vehicle in this segment would be to incorporate **gull-wing doors** (Figure 2.1.1) on one side of the vehicle. On the other side, depending on the market for sale, normal opening doors could be used in order to comply with the safety regulations. The reasons to incorporate this type of door in a personal urban mobility vehicle are:

1. Lower door opening clearance to enable easier access to and from the vehicle in tight parking spaces; and tight parking spaces are very common in urban areas.

2. A large aperture and shade because gull-wing doors aid in easy entry and exit even while using an umbrella or a raincoat (monsoons are prevalent in India unlike Europe as seen in section 1.2. of this thesis).

3. This type of door could also help in achieving a “cool factor” for the vehicle and can be automated for remote opening and closing the door.

Figure 2.1.1: Gull wing doors on a Pagani Huayra [41]

Figure 2.1.2: A representational image for the quadricycle - front view [106]

Figure 2.1.3: A representational image for the quadricycle - side view [106]

Figure 2.1.4: A representational image for the quadricycle - rear three-quarter view [106]


Figure 2.1.5: A representational image for the quadricycle - steering wheel and IP [106]


Figure 2.1.6: A representational image for the quadricycle - rear seat [106]

Figure 2.1.7: McLaren Senna doors with transparent lower half [39]

In addition to the traditional gull-wing doors, a **transparent section** could be added to the lower half of both the doors for more light to enter and to enhance the sense of space in an otherwise narrower than usual cabin (Figure 2.1.7). On the other hand, this transparent section in the lower half of the door could also be used to display embroidered/printed cloth patterns that would allow customers to **personalise** their vehicles while also adding a new accessory division to the manufacturer that could bring in additional revenue. OEM (Original Equipment Manufacturer) personalisation in the suggested price range of this vehicle will be a USP (Unique Selling Proposition) to enable better sales of the vehicle.

2.2. Vehicle dimensions

Inorder to determine the ideal dimensions for such a quadricycle, the main criteria chosen was the government mandated parking lot dimensions for two-wheelers in India. This is because finding a parking lot for a vehicle is one of the major problems while using a personal mobility solution (both cars and motorbikes) in urban India; and the smaller a vehicle is, the easier it is to find a parking lot. Also, having smaller dimensions will reduce the road footprint of the vehicle, which will in turn help to alleviate the traffic congestion on the road [25].

The parking standards (parking lot dimensions) in India are the following [15]:

1. Four-wheeler parking lot size - 2,5m x 5,0m
2. Two-wheeler parking lot size - 1,5m x 2,5m

Based on the above mentioned standards, the suggested dimensions for the quadricycle would be 2,49m x 1,24m x 1,49m (Length x Width x Height)

Figure 2.2.1: Suggested dimensions for the quadricycle

Front cross-sectional area

With lower width in comparison to a compact car, the front cross-sectional area of the suggested quadricycle would be lower and hence the drag force on the vehicle would be lower, thus resulting in energy efficiency for an electric car.

One can compare the estimated cross-sectional areas of two vehicles to understand the difference in drag force for two different types of vehicles, one is a compact car that used to be quite popular in the Indian market, but not in production anymore in India - the Hyundai Eon; the other vehicle is a Renault Twizy - a quadricycle with similar dimensions and design to the proposed quadricycle. Ground clearance of both vehicles was taken at 150 mm in laden condition.

Figure 2.2.2: Front cross-sectional dimensions of a Renault Twizy (Left) and a Hyundai Eon (Right)

Average front cross-sectional area of a compact car [13] = 2,05 m^2

Front cross-sectional area of a similar quadricycle (Renault Twizy) = 1,1 m^2

Drag Force is directly proportional to front cross-sectional area from the following formula:

$$F_D = \frac{1}{2}\rho v^2 C_D A$$

Where,
$\mathbf{F_D}$ is the Drag Force
$\boldsymbol{\rho}$ is the density of the fluid through which the body is moving
v is the speed of the body relative to the fluid
$\mathbf{C_D}$ is the drag coefficient
A is the front cross-sectional Area

If one were to consider the speed of the vehicle and the coefficient of drag of the vehicle to be identical for each of the vehicles respectively, one could say that the quadricycle (Renault Twizy) has almost 50% less drag force acting on it compared to a compact car, thus making the quadricycle a more efficient vehicle.

Space utilization

Space is a premium in any urban environment as stated in Section 1.2 of this thesis. Inorder to understand how the dimensions of the proposed quadricycle adapt to such an environment, a graphical representation was adopted as seen below.

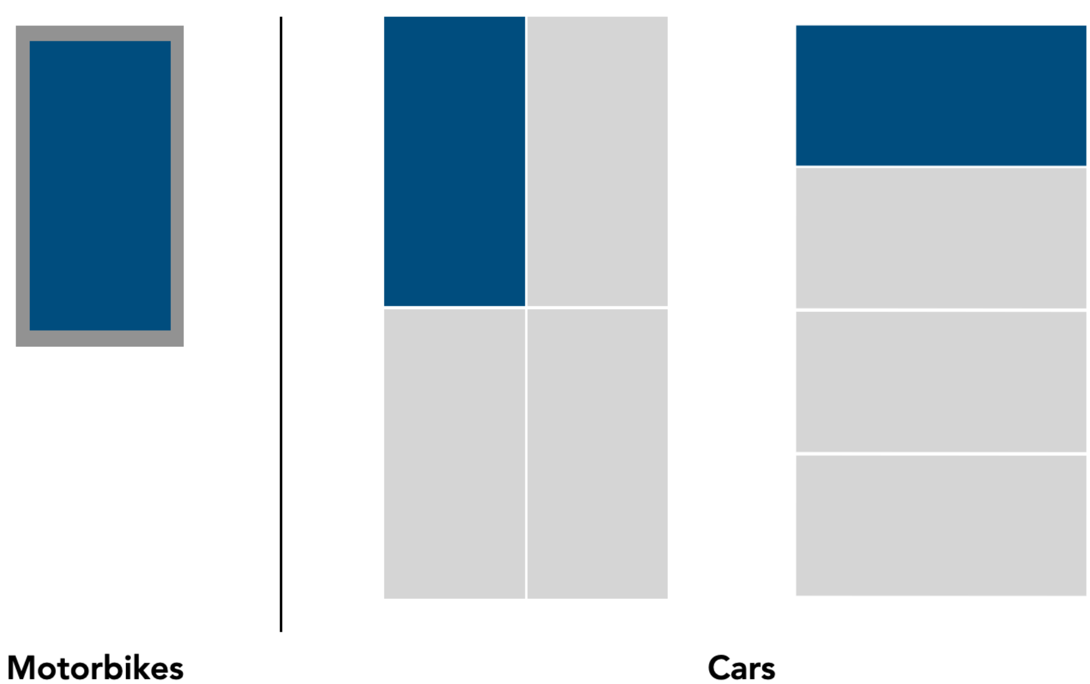


Figure 2.2.3: Parking or road space utilized by proposed quadricycle

For exterior space utilization, Figure 2.2.3 represents the space utilized by a quadricycle (represented in blue colour) inside parking lots allotted for both motorbikes and cars (represented in grey colour) according to the parking standards in India [15]. The quadricycle occupies only the parking lot size of a motorcycle and occupies only 1/4th of the parking lot size of a four-wheeler. Such dimensions put this quadricycle at an advantage compared to compact cars for urban commuting and urban parking scenarios, thus making it easy to use in an urban environment.

It is also interesting to note that parking space prices for residential housing in urban India are increasing at a very high rate while parking facilities are rated as very poor [105]. This scenario presents a very unique advantage for the proposed quadricycle that can fit inside the same parking lot along with another compact car (usually less than 4000 mm). Thus saving the owner the cost of an additional parking space for a second vehicle while also adding another vehicle for increased mobility in the family.

The reason to choose a four wheeled solution rather than a three-wheeled solution is to aid the high speed stability and to maximise the space utilization inside for the given footprint of the vehicle. A three-wheeler will have an intrusion for a wheel and wheel articulation into the cabin, thus minimising the cabin space for a given footprint of the vehicle, which could otherwise be used for interior space, storage or placement of various modules.

2.3. Vehicle modules and layout

The various modules in the proposed quadricycle are shown in Figure 2.3.1 to understand the arrangement and position of the modules. The green lines in Figure 2.3.1 represent the basic layout of the seats. The most important modules of the proposed quadricycle are [20]:

1. Battery pack
2. Electric drive
3. Power electronics
4. Vehicle interface control
5. HVAC

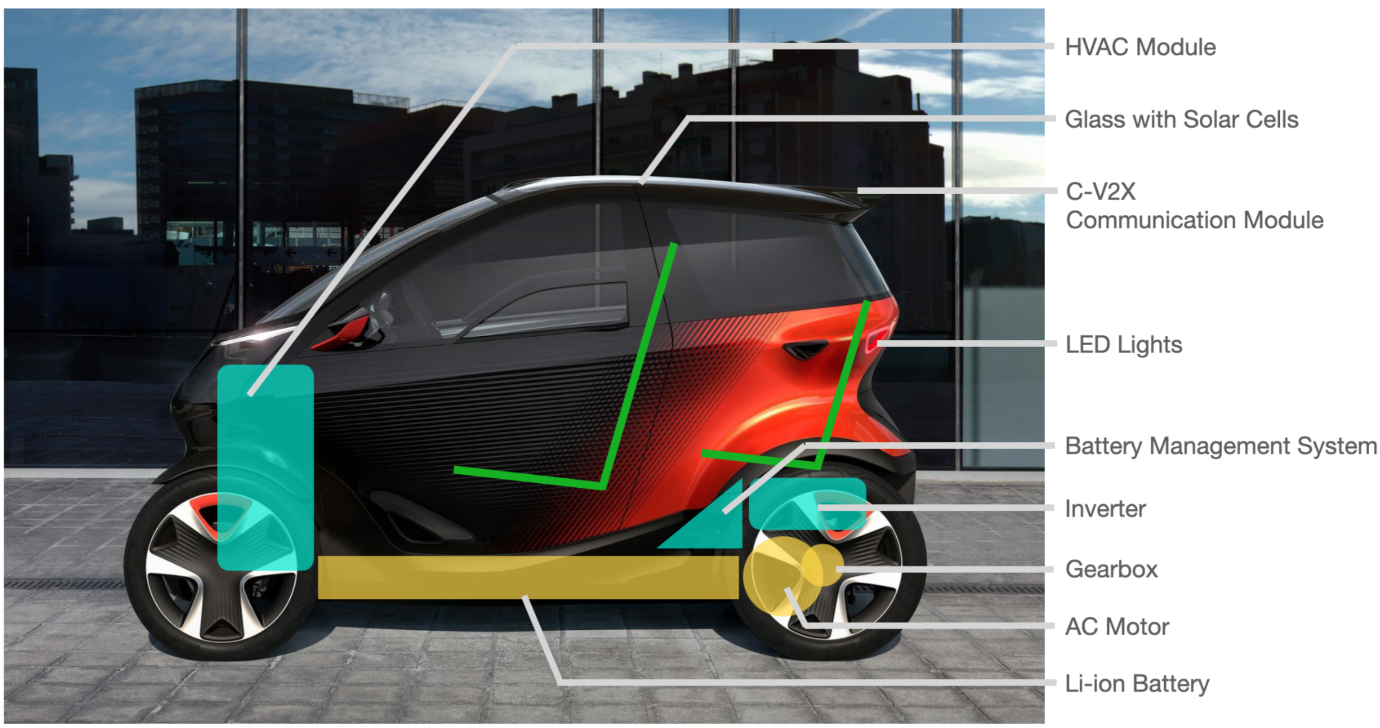


Figure 2.3.1: Arrangement of various modules in the proposed quadricycle

Inorder to suggest a layout of various modules of the proposed quadricycle, the T27 concept by Gordon Murray Design [56] was taken as reference as seen in Figure 2.3.2. The T27 is an electric city car with similar dimensions, weight and seating layout to the proposed quadricycle, albeit the lack of a HVAC system is a notable difference.

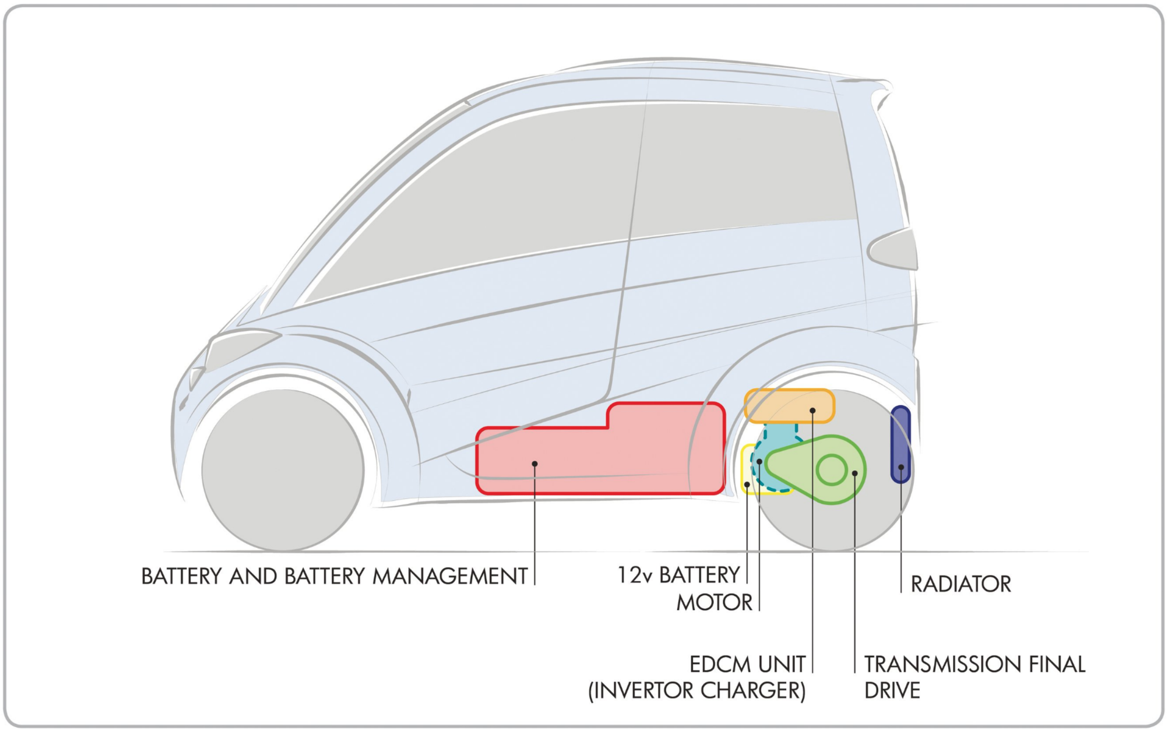


Figure 2.3.2: Reference for vehicle architecture layout [56]

Battery pack

The battery pack module includes battery cell modules, thermal management casing, battery management systems and other mechanical and electronic parts related to the proper functioning of the battery in an EV. The ideal location for the battery pack is on the floor or as the floor of the vehicle, to have better temperature control for the battery and for ideal weight distribution of the vehicle. The battery pack also acts as a structural element for torsional rigidity and impact force dissipation.

Lithium Ion (Li-ion) batteries are the mainstream battery technology in the market for EVs and it is also the direction of the market going into the future. According to a study [53], it is predicted that the Lithium Ion battery will not be replaced by others for a long period of time due to their high performance characteristics.

The basic diagram of a Li-ion battery is shown below in Figure 2.3.3 to explain the mechanism and to understand the chemical reactions better. The Lithium Cobalt di-oxide ($LiCoO_2$) on the left side of the battery forms the cathode and the Graphite / Carbon (C) on the right side of the battery forms the anode.

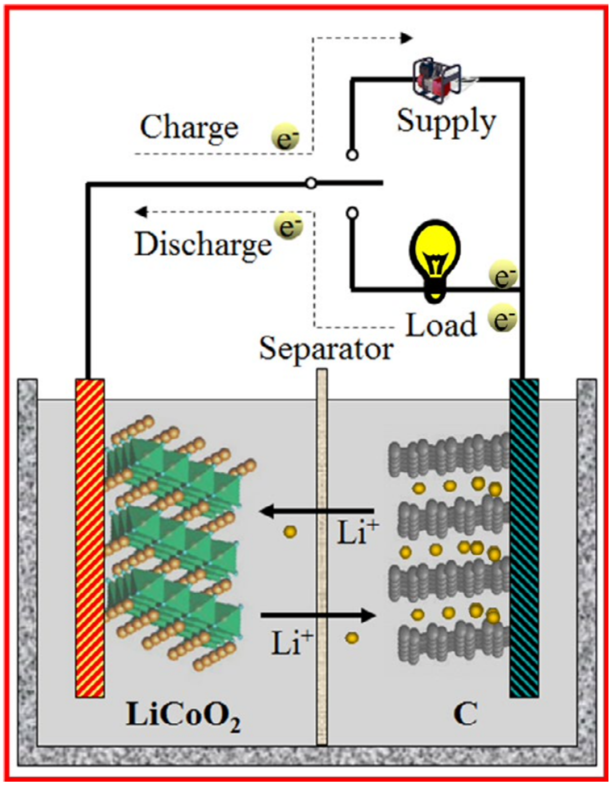


Figure 2.3.3: The basic components and operation principle of a Li-ion cell [57]

Reaction at Cathode: $\mathbf{LiCoO_2 \leftrightarrow 0.5Li^+ + 0.5e^- + Li_{0.5}CoO_2}$

Reaction at Anode: $\mathbf{Li^+ + e^- + C_6 \leftrightarrow LiC_6}$

The main characteristics of a battery that were considered for the purpose of this thesis are the following:

1. **Energy Density**
   The energy density of a battery is the measure of how much energy that a battery can store inside. The energy density is one of the key indicators of performance of battery systems. Sufficient energy density allows for sufficient range and is especially focused on the development at the cell level [55]. Energy density is generally expressed in two ways -

the gravimetric energy density of a battery is a measure of how much energy a battery contains in comparison to its weight, and is typically expressed in Watt-hours/kilogram (Whr/kg). The volumetric energy density of a battery is a measure of how much energy a battery contains in comparison to its volume, and is typically expressed in Watt-hours/liter (Whr/l).

2. **Cell Voltage / Voltage Stability**
   The consistency of the battery pack is described by internal resistance and open-circuit voltage (OCV); it is an important factor affecting their performance. It is demonstrated that battery temperature has the greatest impact on the internal resistance consistency of the battery pack through correlation analysis. The initial SOC (State of Charge) inconsistency and temperature of the battery are two key factors affecting the battery pack consistency based on the operation data, providing a foundation for battery consistency improvement. [53]

3. **Peak Current**
   The maximum current that a battery can deliver is directly dependent on the internal equivalent series resistance (ESR) of the battery.

4. **Self Discharge**
   A very small amount of the chemical substances inside the batteries react even without any attached load. These internal reactions reduce the stored charge of the battery and thus decrease the capacity of the battery little by little. This phenomenon is called self-discharge.

5. **Recharge Time**
   It is the time taken by the battery to reverse the electrochemical reactions in order to store energy. Li-ion batteries used in electric vehicles may take long, for example, overnight, to get fully charged, although it could be quickly charged to a certain low SOC at high current with special charging devices. One of the active research directions in Li-ion battery field is to increase the performance so that the time consumed for charging a battery can be dramatically reduced, which is particularly crucial to the market acceptance of electric vehicles

6. **Cost**

   Cost of the battery for large scale requirements would always be calculated for cost per kW rather than per cell. Battery costs have come down to $137/kWh in the market, while in the Chinese market the price was around $100/kWh according to reports [55]. The prices of batteries shall be discussed in detail in the following topics of this thesis.

According to a study [54], it was demonstrated for the first time anywhere that lithium-ion batteries are outstanding battery systems not only in terms of capacity, but also with respect to their high power characteristics. The system is improving, but more than ever, specific energy is improving more than energy density. However improvements are to be gained in packaging optimization and could be a next step in battery system development. Other aspects that are relevant to batteries are cell types and sizes.

According to the type of batteries available in the market, batteries can be classified into the following types [54] :

1. Cylindrical battery
2. Pouch type battery
3. Prismatic battery

Figure 2.3.4: Types of batteries [59]

According to the study [54], the energy density of the various cells were recorded experimentally at both cell level and system level to understand the performance characteristics of each type of cell due to packaging. A graphical representation of the recorded data is shown in Figure 2.3.5. It is interesting to note that cylindrical cells have the highest specific energy both at cell level and at system level. One result of the experiment was that specific energy on system level seems to be mainly a question of cell chemistry; many of the systems assessed have a quite low energy density as compared to their respective cell energy density and that the range of energy density between vehicles is very high. The study also states that the influence of efficient packaging is very strong for reaching high driving ranges because spare volume is scarce in vehicle design and packaging is not always done very efficiently, but efficient packaging means more space for cells.

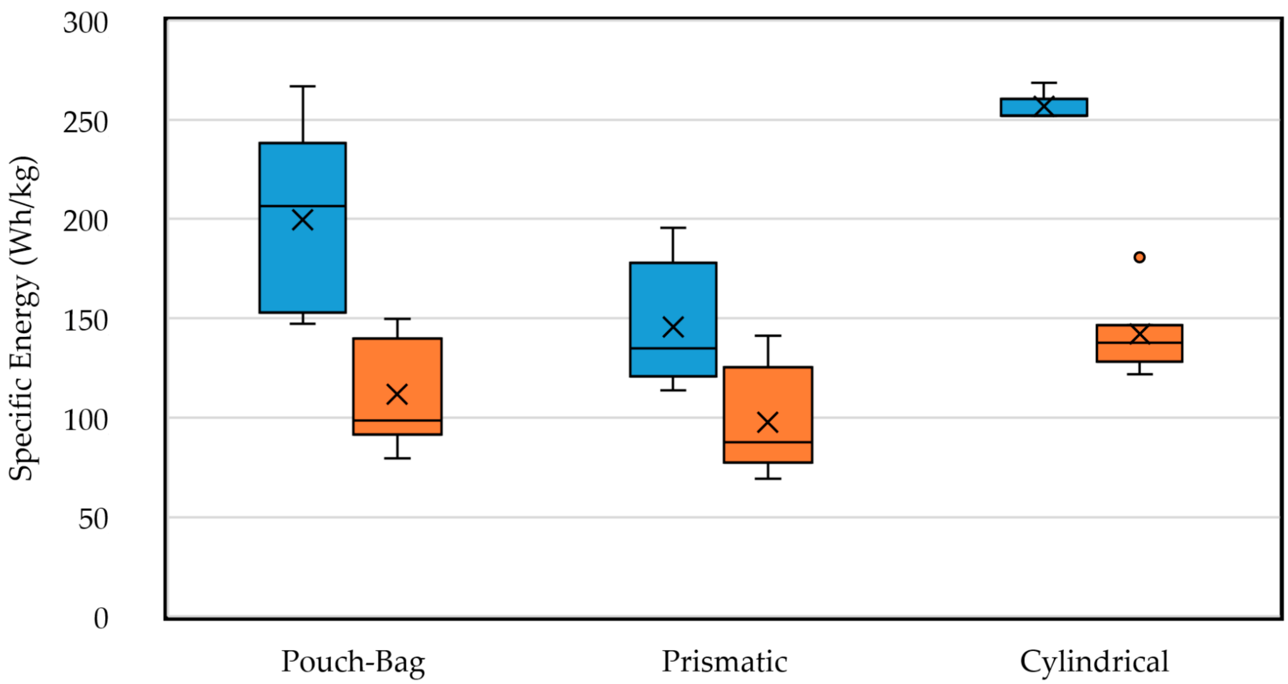


Figure 2.3.5: Type and Energy Density on Cell Level (Blue) and System Level (Orange) from the study [54]

In order to understand the highest achievable system energy, a theoretical estimation was conducted in the study. The best system available in the market has a specific energy of 181 Wh/kg, the cell with the highest specific energy is at 269 Wh/kg, the best cell-to module efficiency is 0,926 and the best module to system efficiency is 0,885. Already the current systems in the market can achieve a specific energy of 220 Wh/kg, which is an improvement of about 22% from the previous best result achieved. According to the study, it is also theoretically possible to have a system that has an energy density of 629 Wh/L. However, this theoretical value can be limited by other factors such as cooling system, cell type and system configuration; but the value shows the possibility towards achieving this high figure. [54]

To estimate a battery pack size for the proposed vehicle, various EVs in the market were considered to understand the battery pack size, weight and range inorder to determine the range per kW and Weight of vehicle per kW to compare the vehicles. Table 2.3.1 lists the various parameters considered for the estimation.

SNo.	Vehicle	Kerb Weight (kg)	Range (km)	Testing cycle or Authority	Battery size (kW)	Weight / kW	Range / kW
1	Tata Nexon	1400	312	ARAI	30,2	46,36	10,33
2	Nissan Leaf	1580	270	WLTP	40	39,50	6,75
3	Hyundai Kona	1535	305	WLTP	39,2	39,16	7,78
4	MG ZS EV	1609	262	WLTP	44,5	36,16	5,89
5	Tesla Model 3	1645	430	WLTP	54	30,46	7,96
	Averages	1553,8	315,8	-	41,58	38,33	7,74
6	Proposed Quadricycle	600	200	-	17	35,29	11,76

Table 2.3.1: Battery pack capacity estimation [107]

For estimating the size of battery pack for the proposed vehicle, the ratios of weight per kW of battery and range per kW of battery were considered to co-relate the data from various vehicles and take averages as seen in Table 2.3.1. Then the estimated weight and range of the proposed vehicle were entered and the ratio of weight per kW was matched closer to average by trying different battery sizes.

Since the quadricycle is considered for urban use, the range would be higher inside the city due to stop and go traffic and higher brake usage frequency resulting in a higher brake energy regeneration and thus a higher range per kW figure would be justified. Also the proposed quadricycle's lower front cross sectional area will aid in achieving a better efficiency than the compared vehicles and thus a higher range per kW figure than other vehicles was adopted.

Based on the above mentioned assumptions and data, the ideal battery pack size for the proposed quadricycle was estimated to be between 15 kW and 17 kW for a maximum urban driving range of 200 km.

Electric drive

In electric vehicles, the traction motor or the e-motor is a major component for propulsion. The desirable characteristics of such a motor are high torque, good efficiency, wide speed range, high reliability, low noise and vibration, and reasonable cost [61]. The suggested location for the e-motor is at the rear of the quadricycle to incorporate a rear-wheel drive setup which is more favoured among enthusiasts.

The general parameters considered for all electric motors are:

1. **Motor Torque**
   Torque is a vector physical quantity equal to the product of the radius-vector, drawn from the axis of rotation to the point of application of force, by the vector of this force.

$$M = Fr$$

where,
M – torque, Nm
F – force, N
r – radius-vector, m

2. **Motor Power**
   Motor power is the useful mechanical power at the motor shaft. Power is a physical quantity that shows what kind of work the mechanism performs per unit of time.

$$P = \frac{dA}{dt}$$

where,
P – power, W
A – work, J
t - time, s

Work is a scalar physical quantity equal to the product of the projection of the force on the direction F and the path s is traversed by the point of application of force.

$$dA = Fds$$

where,

s – displacement, m

For rotational motion

$$ds = rd\theta$$

where,

θ – angle, rad

$$\omega = \frac{d\theta}{dt}$$

where,

ω – angular velocity, rad/s

Thus it is possible to calculate the value of mechanical power on the shaft of a rotating electric motor.

$$\boxed{P = M\omega}$$

3. Energy Conversion efficiency

Energy conversion efficiency of the electric motor is a characteristic of the machine's effectiveness in relation to the conversion of electrical energy into mechanical energy.

$$\eta = \frac{P_2}{P_1}$$

where,

η - efficiency of electric motor

P_1 - input power

P_2 - useful output power

4. **Moment of Inertia of motor**

The moment of inertia - a scalar physical quantity, which is a measure of the inertia of a body in a rotational motion around an axis, is equal to the sum of the products of the masses of material points and the squares of their distances from the axis.

$$J = \int r^2 dm$$

where,

J - moment of inertia, kg/m^2

m - mass, kg

5. **Rated Voltage**

Rated voltage is the voltage to which the power grid or equipment is designed and to which their characteristics are referred. [66]

6. **Electric Time Constant**

The electrical time constant is the time counted from the moment a DC voltage is applied to the electric motor, during which the current reaches a level of 63.21% (1-1/e) of its final value.

$$\tau_e = \frac{L}{R}$$

where,

τ_e - time constant, s

L - Armature inductance

R - Armature resistance

7. **Rated Speed**

Rated speed refers to the rotational speed of the motor.

$$n = \frac{30 \cdot \omega}{\pi}$$

where,
n - rotational speed of motor, rev/s

Electric motors are a crucial component in the electric vehicle drivetrain. There are various types of electric motors available in the market, the most relevant electric motors available in the market are of the following types:

1. **Interior Permanent Magnet Synchronous Motor (IPMSM)**

   A permanent magnet synchronous electric motor is a type of electric motor whose inductor consists of permanent magnets. This type of motor is the best option available in the market for their high performance characteristics; they are used in the Nissan Leaf and the Toyota Prius. They use rare-earth magnets to achieve these high performance characteristics, but the material cost of rare-earth magnets is often high and the supply of the material is controlled by few countries. [62]

   Permanent magnet synchronous motors are very efficient, brushless, very fast, safe, and give high dynamic performance when compared to conventional motors. It produces smooth torque, low noise and is mainly used for high-speed applications like robotics. It is a 3-phase AC synchronous motor that runs at synchronous speed with the applied AC source. [67]

2. **Copper Rotor Induction Motors (IM)**

   Any electric motor consists of two main parts - the stator and the rotor. The stator is a stationary part, the rotor is a rotating part. Usually, the rotor is located inside the stator. Tesla uses this solution without rare earth metals to maintain the costs. However, a particular disadvantage of this type of motor is that the starting current of IMs can be high and this is disadvantageous for battery duration. [62]

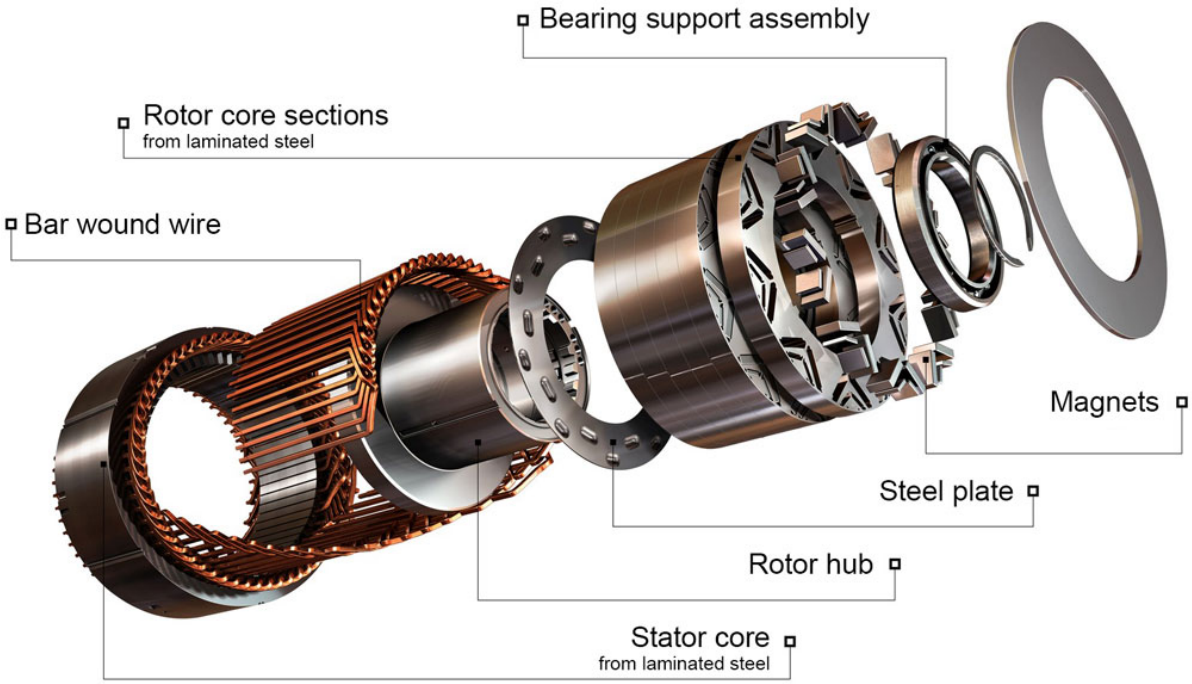


Figure 2.3.6: Exploded layout of an interior permanent magnet synchronous motor [62]

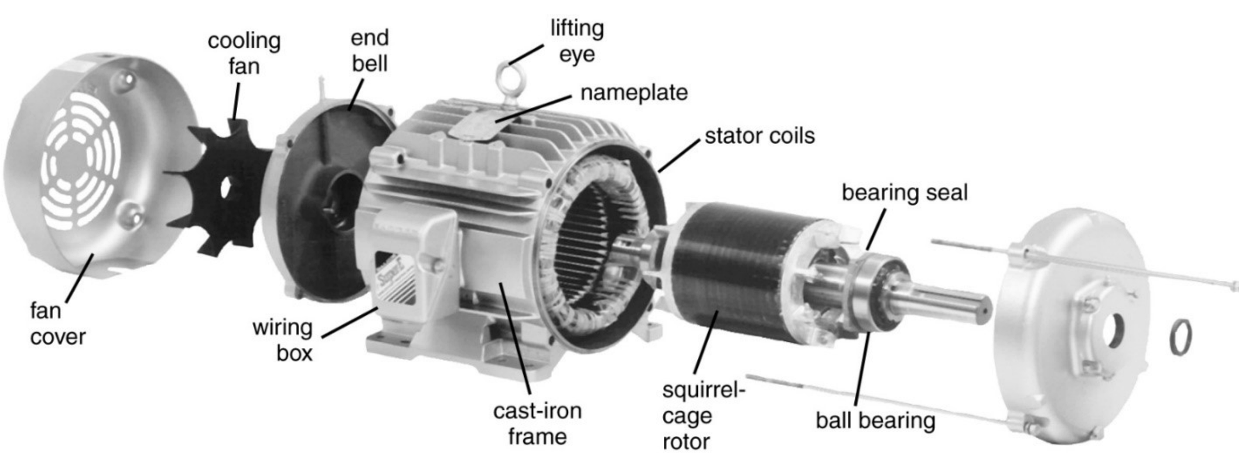


Figure 2.3.7: Exploded layout of an induction motor [63]

3. **Permanent Magnet Assisted Synchronous Reluctance Motor (PMa-SynRM)**

Synchronous reluctance technology combines the performance of the permanent magnet motor with the simplicity and service-friendliness of an induction motor. The rotor has neither magnets nor windings and suffers virtually no power losses. And because there are no magnetic forces in the rotor, maintenance is as straightforward as with induction motors. The rotor should be well designed in order to gain as much reluctance torque as possible as seen in Figure 2.3.8. With a good design, for the same current input, the SynRM motors can deliver 10-15% more torque than induction motors and upto 5% more efficiency (the lower power loss in induction motors is mainly due to heating of copper coils). Tesla has started using SynRMs in their vehicles recently and a similar case is being reported in other industries due to SynRMs remarkable performance. [64] [65]

Based on the above mentioned advantages of SynRM, it would be ideal to use a SynRM motor in the proposed quadricycle and operate without any power losses. However, it is important to take the cost of the component also into consideration while looking at available solutions as the thesis is to understand the possibility of making an affordable electric vehicle.

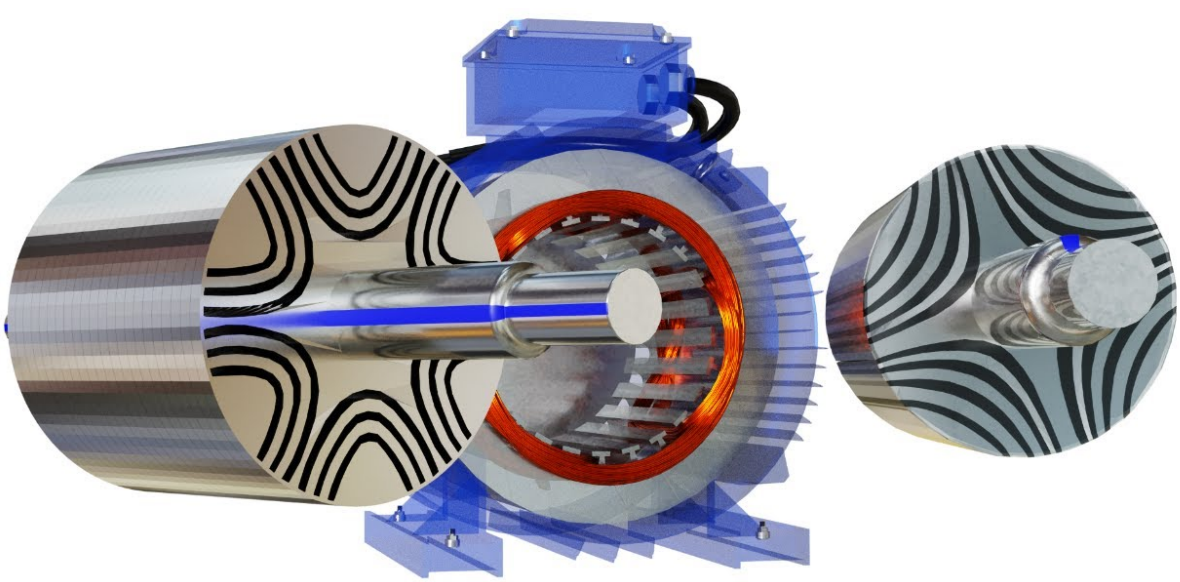


Figure 2.3.8: Exploded view of SynRM motor and rotor types [64]

Power electronics

The power electronics modules of an EV include power distribution modules, DC converters, thermal management, charger systems and others to name a few.

Power Distribution Unit (PDU) [70]

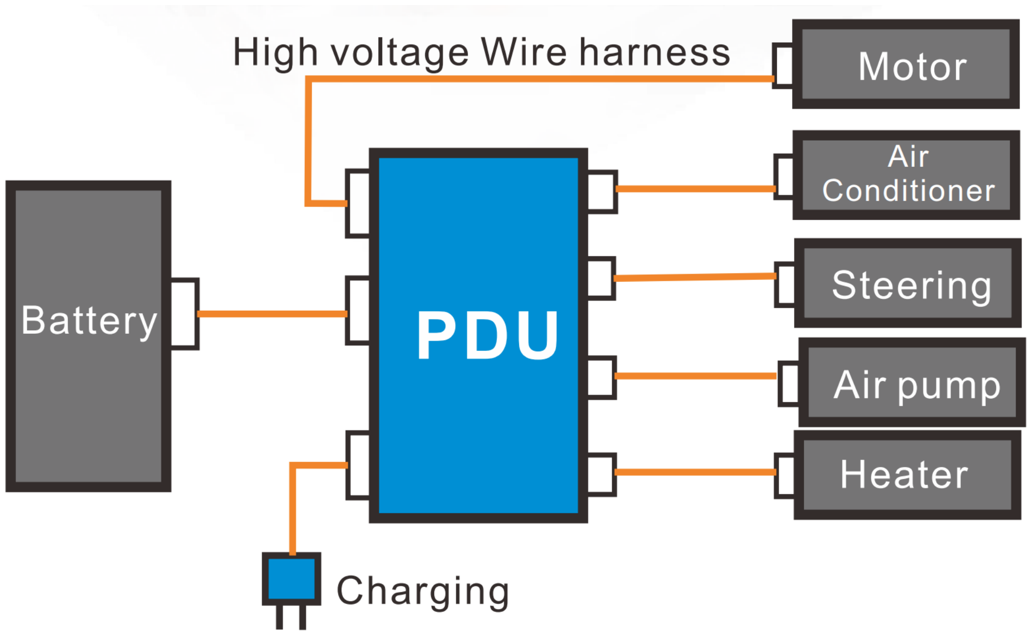


Figure 2.3.9: Application diagram of power distribution unit [70]

The electric vehicle high voltage power distribution box also known as "Electric vehicle power unit" or "Electric vehicle safety box", is an important module in an EV. It supports the function of converting and distributing power to every systematic unit such as motor control unit, battery management system, charging system, DC to DC converter system, air condition system, electric steering auxiliary system and brake system. PDU can also provide short circuit protection, current leaking protection and high voltage and current protection. Battery lifespan is longer and maintenance cost of EV is reduced with this unit because of it's easy maintenance, convenient installation, space saving and reliable electric connection characteristics. Figure 2.3.9 shows the application diagram of a PDU with its high voltage wired connections to various modules. [70]

Thermal management of battery pack [68]

New generation EVs require high energy density battery packs to increase power output and also extend the range of the EV for the given weight of the battery. In this thesis, cylindrical batteries were considered for the proposed electric vehicle, however packaging the battery is also as important as the choice of the battery, because if the optimum temperature of the battery is not maintained, the battery will deteriorate. And extreme temperature in batteries can affect its performance, reliability, safety and lifespan; thus thermal management of the battery system is critical to the success of all electric vehicles. The optimum operating temperature range of a battery pack was found to be between 0 ℃ and 40 ℃.

There have been various methods for temperature control in batteries, the basic principle is to improve the heat transfer areas between air flow and battery surface to improve battery cooling efficiency. Some of the various types of battery cooling systems are:

1. **Air cooling thermal management system**
2. **Liquid cooling thermal management system**
3. **Phase change material thermal management system**

Out of the three cooling systems mentioned above, the air cooling thermal management system is considered to be simple in design, very reliable and costs lower than other cooling systems [68]. As per a study [68] to analyse the forced air cooling of a densely-packed battery box, numerical simulation was used to explore the air cooling capability on the temperature uniformity and hotspot mitigation under various flow paths, airflow rates. Based on the research, the following conclusions were drawn:

1. The maximum temperature of the battery pack decreases gradually with the increasing size of cooling channels through the battery pack.

2. The rate of decrease in maximum temperature decreases gradually with the increase in cooling channel sizes; this shows that the continuous increase in cooling channel sizes is not the best method to lower the maximum temperature.

3. In the study, the maximum temperature difference of the densely-packed battery box was decreased with the improvement of effective heat transfer areas between air-coolant and battery surfaces.

DC/DC Converter in EVs [69]

A DC to DC converter is a category of power converters and it is an electric circuit which converts a source of direct current (DC) from one voltage level to another, by storing the input energy temporarily and then releasing that energy to the output at a different voltage. The storage may be in either magnetic field storage components (inductors, transformers) or electric field storage components (capacitors).

Energy storage or supply devices vary their output voltage with load or state of charge and the high voltage of the DC-link creates major challenges for vehicle designers when integrating energy storage / supply devices with a traction drive. DC-DC converters can be used to interface the elements in the electric powertrain by boosting or chopping the voltage levels.

Due to the stringent standards in the automotive industry, the DC-DC converters have to be reliable, lightweight, small volume with high efficiency, low electromagnetic interference, and low current or voltage ripple.

The different types of DC-DC converters are:

1. **Conventional step-up dc-dc converter,**
2. **Interleaved 4-channels step-up dc-dc converter with independent inductors**
3. **Full-Bridge step-up dc-dc converter**

EV Charging / Charger System [71]

There are various types of EV chargers, based on their power ratings EV chargers can be divided into 3 types, with the specifications given in Table 2.3.2 below:

SNo.	Power Level	Charger Location	Typical Use	Typical Power	Charging Time	Connector
1	Level 1	On-board	Home	2kW	4 - 11 hrs	SAE J1772
2	Level 2	On-board	Public	20kW	1- 4 hrs	SAE J1772
3	Level 3	Off-board	DC Fast	100kW	<30 min	CHAdeMO / CSS / Combo 2

Table 2.3.2: Charging power levels and specifications [71]

The battery charger can allow for an unidirectional or bidirectional power flow at all power levels. The bidirectional power flow adds to the grid-to-vehicle interaction (G2V) also the vehicle-to-grid (V2G) mode. While it is important to determine the charging technology, the charging method is also as important for an EV. The main charging strategies to recharge Li-ion batteries are constant-current/constant-voltage (CC/CV) and pulse current charging methods.

The EV charging technology is broadly divided into two:

1. **On-board charger**

   Onboard battery chargers (OBC) are limited by size, weight and volume, for this reason they are usually compatible with Level 1 and Level 2 chargers. They usually have unidirectional capability, but in some configurations bi-directional capability can be achieved. Onboard charger can be further divided into two-stage and one-stage. Onboard chargers with two stages are usually composed of an AC–DC stage in the front end and a DC-DC stage in the back end. If the AC-DC rectifier is combined with a DC-DC rectifier, then we obtain a single stage charger.

2. **Off-board charger**

   Level 3 chargers because of their high power ratings are usually installed outside the vehicle, hence they are called off-board chargers. The off-board charging system is most commonly com- posed of two stages - a grid-facing AC/DC converter followed by a DC/DC converter providing an interface to EV.

Fast Charging Stations

To reduce the driving range anxiety and to support an increase in market penetration of EVs worldwide, there was a need for a charging system which is able to replace the current existing gasoline stations and hence Fast Charging Stations (FCS) came into existence. But in order to charge a battery, it requires one to understand the type of batteries and their characteristics. Based on various studies, Li-ion batteries were found to be the best options available [53].

The advantages of a lithium-ion battery over other types of energy storage devices are high energy and power density, low memory effect and low capacity loss, making this type of battery the most suitable option for EVs. However, charging the battery is an important factor in increasing the longevity of the battery. An optimised charging method will ensure that the electrochemical reactions inside the cell that produce electricity are active; thus a suitable charging method has to be adopted to ensure that the battery will be charged in the shortest period of time possible with high efficiency and without damaging the cells. According to a study [71] and based on the above recommendations, some of the various methods of charging that are available in the market are as follows:

1. **Constant Current - Constant Voltage (CC-CV)**

   In this method, both an initial constant current and a final constant voltage are used. The charging process starts with a constant current until a certain cut-off voltage is reached. And thus charging the battery until full.

2. **Five Step Charging pattern**

   The five-step charging pattern is a multistage (five stages) constant-current charging method, in which the charging time is divided into five steps. In each stage, the charging current is set to a constant threshold value. During charging, the voltage of the battery will increase and when it reaches the preset limit voltage, the stage number will increase and a new charging current set value will be applied accordingly, thus charging the battery until it is full.

3. **Pulse-Charging method**

   In this method of charging EV batteries, electricity is injected into the battery in the form of pulses in order to provide a rest period for the ions to diffuse and neutralise. The charging rate that depends on average current can be controlled by controlling the duration of pulses. This method of charging is claimed to decrease the charging time, slow down polarization and increase life cycles.

Vehicle control unit

The Vehicle control unit (VCU) or the Vehicle control system (VCS) is a very important part of any vehicle. The VCU module is very complex, distributed on several electronic control modules and with a lot of interactions with other vehicle systems like braking, heating and ventilation, battery management, etc. [73]

For example, the VCU takes a variety of driver inputs and calculates a torque value to be sent to the inverter. This torque value is proportional to the accelerator and brake pedal positions as well as the gearbox setting and is arbitrated via any other vehicle torque demands, such as from the electronic stability control system. [72]

The VCU is connected to the following hardware of the vehicle in most cases:

1. Powertrain
2. High Voltage Battery
3. Vehicle (Body)
4. Brakes

The VCU software shares data with the following modules and their respective softwares in most cases:

1. Electric machine control system (EMCS)
2. Stability control system (SCS)
3. Battery management system (BMS)
4. Driver mode system (DMS)

The VCU processes signals from these modules and hardware to perform the aforementioned vehicle functions like braking, heating and ventilation, battery management, etc. in a pre-programmed manner in order to ensure various parameters for safety, driveability, efficiency, comfort and entertainment. The Figure 2.3.10 below shows the various signals and their flow inside the VCU in order to understand the various functions of each module.

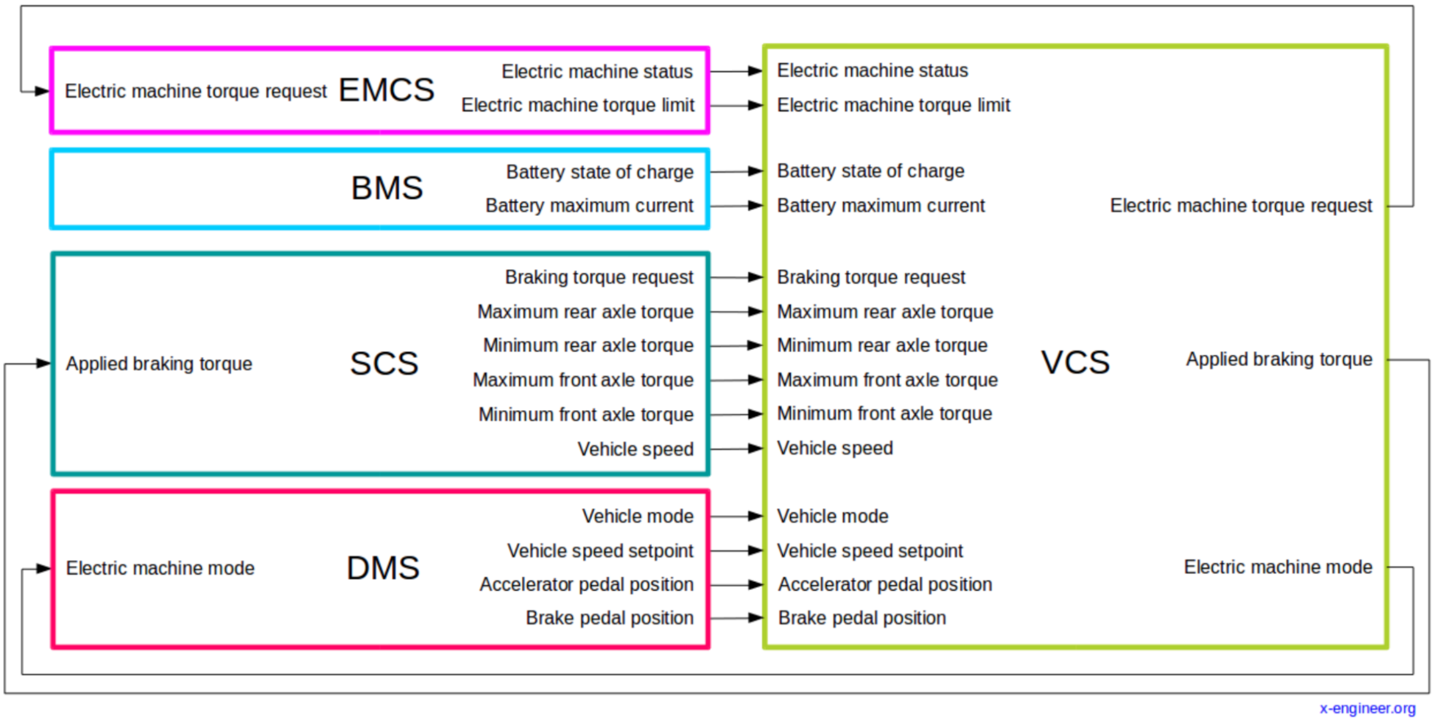


Figure 2.3.10: Signal interface between major electronic control modules [73]

The four main modules, namely - Battery pack, Electric drive, Power electronics and Vehicle control unit are the most important modules in an EV. These four modules contribute approximately 60 % (+/- 10 %) of the total component costs across the considered EV categories. The cost of these components – especially the battery pack – will be the primary driver for the reduction in the cost of EVs. [20] And with a steady reduction in battery prices every year, EVs will be more affordable than conventional IC engine cars in the future.

HVAC unit

The HVAC (Heating Ventilation and Air Conditioning) system in a conventional IC (Internal Combustion) engine car works on a variable displacement mechanical compressor (for latest vehicles), but when it comes to electric cars, this unit will need to be replaced by an electric compressor but with the same variable displacement. The ideal location for the unit is at the front of the quadricycle to have a high pressure area for air intake, this also because of lack of space to fit the unit elsewhere in the proposed vehicle.

The HVAC system has the highest power consumption of all the auxiliary components of the EVs. The energy available for EVs propulsion is stored in the battery pack, so any additional power consumption will result in a reduction of the driving range. Generally, HVAC systems cause about a 30–40% average decrease in driving range depending on the size of AC and the driving cycle for EVs. But the driving range can only be increased by reducing battery power consumption, which requires the development of a highly efficient HVAC system. Thus the HVAC system is crucial to the development and sales of EVs [75].

According to a research paper [74], a 42V air conditioning system was found to be very effective in maintaining a stable and comfortable cabin in hot weather conditions, however while operating the heater, the system was found to reduce the driving range by almost 24% due to its low energy efficiency. Solar assisted heat pump AC systems are another interesting approach towards climate control as it helps to reduce the peak cooling loads significantly and enhance the driving range. In addition to maintaining the climate of the cabin, the HVAC system also plays a crucial role in the thermal management of the battery. Table 2.3.3 shows various AC systems with their advantages and disadvantages.

The VCR-DH solution is widely adopted in IC engine vehicles, but the system has the disadvantage of high electricity consumption. The VC-HP system is more preferred for EVs because of its higher energy efficiency and easy adaptability for use in different EVs with less modifications. This system has some challenges such as reduction in heating capacity and energy efficiency in cold weather, alternative refrigerant etc. But these challenges can be overcome by technologies such as EVI cycle, innovative defrosting methods, hybrid source heat pump and heat pump systems using low GWP refrigerants or natural refrigerants. [75]

The TES system can extend the range of the vehicle in an inexpensive way, and it could be the preferred solution if specific thermal energy density of the TES material is much more than the energy density of batteries. Otherwise, it is suggested to add equivalent battery mass for the AC system and thus extend the range when additional batteries are not used by AC. [75]

The ITM system that combines the AC and battery pack is the future, but the system will face challenges of complex structure, battery descaling and higher requirements of control on the system. [75]

AC Type	Sub-type	Advantages	Disadvantages
VCR-DH (Vapour compression refrigeration - Dedicated heating) systems	VCR-EH (Vapour compression refrigeration - Electric heating) systems	Low noise	Heating COP < 1
		Simple	Cause serious range problems
		Reliable	Alternative refrigerant issue
	VCR-FH (Vapour compression refrigeration - Fuel Heating) systems	Reliability	Not a real zero emission vehicle subsystem
		Simplicity and economy	Two different fuels are needed
		Little influence on the driving range	Alternative refrigerant issue
VC-HP (Vapour Compression heat pump) systems		High capacity density	Range loss at low outdoor temperature
		Compact system	Lower COP under extreme conditions
		Normally COP > 1.0	Control strategy
		Current AC technologies can be used	Component re-design
			Alternative refrigerant issue
Non-VC (Vapour Compression) systems	TES (Thermal energy storage) system	Energy efficient	Cumbersome
		Continues high performance running	Lower energy density of TES materials
	AC systems using TE (Thermoelectric) or ME (Magnetic effect)	Quiet	Less capacity density
		Compact system	Lower COP
		Easy mode switch	Driving range losses
		No alternative refrigerant issues	
	WHD (Waste heat driven) systems	Energy efficient	Insufficient waste heat for PEVs
	Solar-assisted AC systems	Energy efficient	Discontinuous nature of solar energy
		Cooling load reduction	
		Able to recharge the battery	
	Air cycle heat pump system	Environmentally friendly	Low volumetric refrigerating/heating effect
		Air - abundantly available	Poor energy efficiency
		Maintenance is simple and cheap	Noise
			High rotation speed of rotors
ITM (Integrated thermal management) systems	Air cooling	Low cost	Bad heat transfer performance
		Simple	High air mass flow
		Space saving	Dust deposit
			Heating the battery is a challenge in cold winter
	Evaporative cooling	Compact	Need conflict between AC and battery pack
		Good heat transfer performance	Battery descaling
			Heating the battery is a challenge in cold winter
			Not enough experimental results available
	Secondary loop cooling	Energy-efficient	Complex system
		An ideal solution	Battery descaling
			Not enough experimental results available

Table 2.3.3: Comparison of main solution of AC for EVs [75]

2.4. Vehicle features and technical specifications

The proposed quadricycle will require the latest and most intriguing features to capture new customers and admirers alike. Also, the proposed quadricycle should include the most common features in any compact car market that is available in the market like ABS, Air Conditioning, Airbags, Ventilated Seats, Brake Energy Regeneration, Connected Car, LED Lights, Infotainment Touchscreen, Sustainable Interiors, Wireless Charging / USB-C, HiFi Music System, Apple CarPlay / Android Auto, etc. Some of these special features for the proposed quadricycle are discussed below. The suggested technical specifications of the proposed quadricycle are listed in Table 2.4.1 below:

Technical specifications	
Weight *	< 450 kg (Dry Weight)
Max Continuous Rated Power *	< 15 kW
Battery Capacity	15 - 17 kWh
Range	200 - 300 Km
Seating Capacity	2 No.s
Top Speed *	< 70 km/h

Table 2.4.1: Suggested technical specifications for the proposed quadricycle

*Weight and power output should be less than the specified number in-order to qualify for quadricycle category L7 according to norms by ARAI. [11]

Roof with integrated solar panel

Among the various sustainable energy resources, solar energy is considered to be very promising due to its abundant supply, universality, high capacity, and environmental friendliness. The integration of photovoltaic panels in EVs is an attractive proposition due to the advances in terms of PV (Photovoltaic) panel technology, and to the reduction in their cost. [42]

A solar panel on an electric vehicle may be the first step to maximize the benefits of EVs, especially in India, but an optimization of the whole electrical system would be required. Particular attention has to be paid in maximizing the net power from solar panels (solar radiation incidence angle), and in adopting advanced solutions for power electronics. Moreover, these vehicles would require specific solutions for energy management and control, with more advanced look-ahead capabilities. [42]

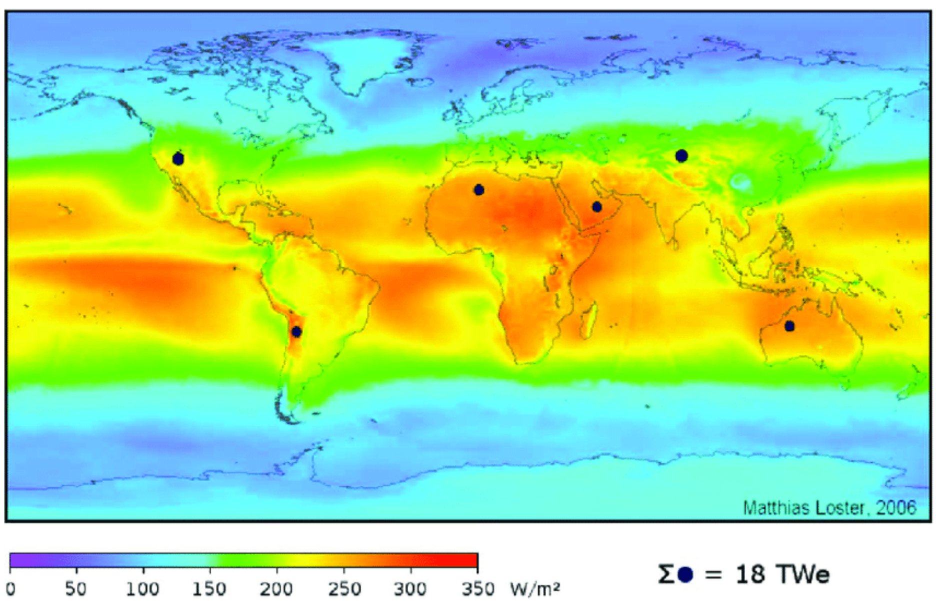


Figure 2.4.1: Annual average solar irradiance distribution over surface of the Earth [42]

The limitations of solar energy are: it is intermittent, due to the effects of relative motion between Earth and Sun, and variable in time, due to weather conditions. But the most serious limitation for direct automotive use concerns its energy density: the amount of radiation theoretically incident on the Earth surface is about 1.360 W/m^2 and only a fraction of this energy can be converted as electrical energy to be used for powering electric cars.

However, as seen in Figure 2.4.1, the average annual solar irradiance over India is near to 250 W/m^2 , which is significantly more irradiance than what is obtained in most parts of Europe and China. With the efficiency of solar panels reaching almost 23%, installation of solar panels on vehicle roof sections could be done to maximise the usage of renewable energy. Even though the amount of solar energy obtained through solar panels will not be adequate for continued vehicle propulsion or to charge the battery fully, the stored energy can be used to operate accessories like the music system, HVAC and communication modules.

LED lights for energy efficiency

LED (Light Emitting Diode) Car Headlights are more energy efficient than halogen or other headlights, they draw less energy from the vehicle which in turn increases the fuel efficiency and makes the vehicle more economical to run. The critical factor in such calculations is the frequency of use of various functions. It even provides a clearer and more effective view of the road at night as it emits two times more visible light than normal halogen bulbs. It is important to note that no other vehicle (other than electric two-wheelers) in the suggested price range offers LED lighting.

These lights are long lasting and can last upto five times longer than halogen and incandescent bulbs. In addition to that, LED lights offer the highest level of sustainability, durability and efficiency. Due to the maximum number of benefits, the demand and popularity of these lights is also very high.

According to a study conducted to understand and analyse the efficiency of LEDs over halogen lights in automotive application [44], it was found that a reduction in daytime power requirement by almost 70% was achieved in comparison to conventional incandescent and halogen lighting. And a reduction of almost 50% in the night time power requirement was achieved during the tests.

Also according to the study [44], annual distance saving for the electric vehicle is approximately 80% higher for both day and night driving for all conditions. These savings ranged from 60 km to 106 km for the gasoline-powered vehicle and from 107 km to 191 km for the electric vehicle every year for a nominal usage pattern. Figure 2.4.2 shows the potential distance savings for different types of vehicles (both gasoline and electric) per 100 km distance travelled.

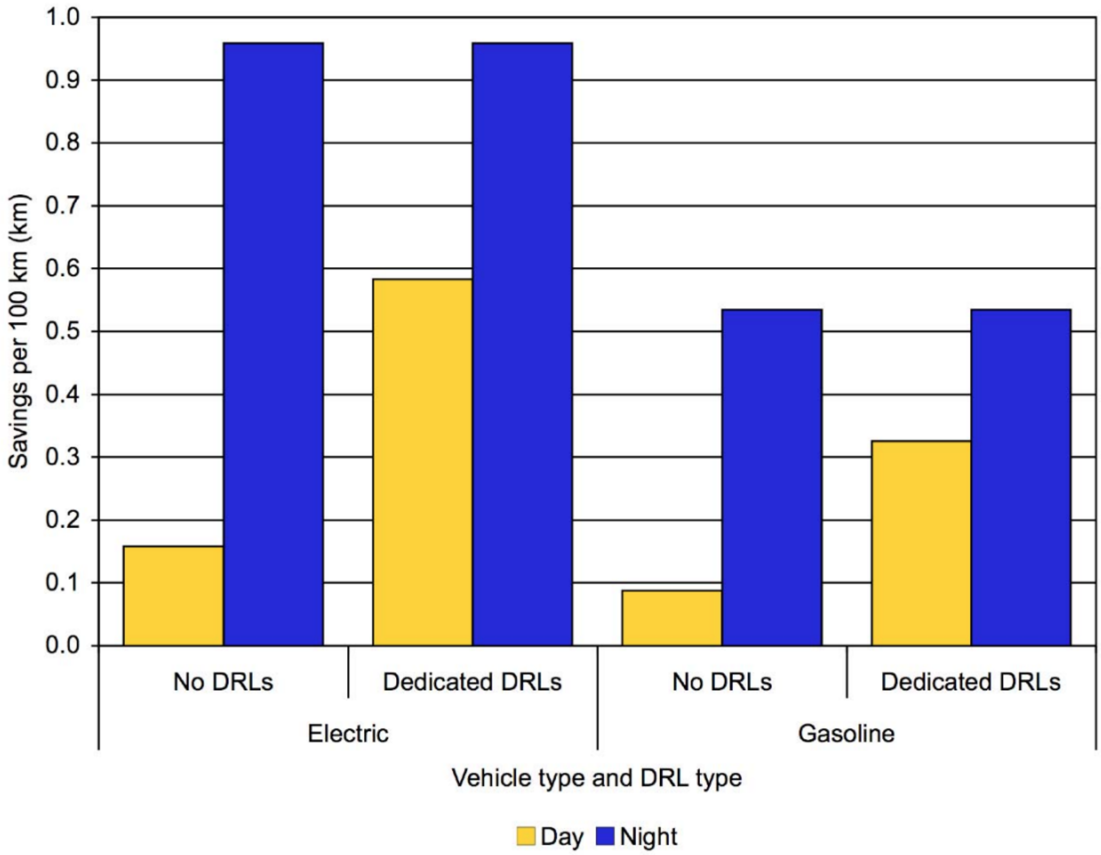


Figure 2.4.2: Potential distance savings (km) per 100km [44]

oLED Instrument cluster and smartphone holder

oLED (Organic Light Emitting Diode) with customisable display and animations to indicate various vehicle parameters like speed and other vehicle data are one of the divisions where auto manufacturers have been investing more than before. These displays are drastically different from the old analogue instrumentation, and are more appealing to younger customers who are accustomed to animated games and smartphone apps. Figure 2.4.3 shows the latest trend in the automobile market - a large oLED touch-screen (1,42m diagonal length) with graphical displays provided as an option to choose in the new Mercedes-Benz EQS production variant. These oLED displays are more efficient, more durable and operate in a wider temperature band than the LCD displays that are being replaced increasingly in automobiles.

Figure 2.4.3: Futuristic Mercedes-Benz EQS with full-dashboard oLED display [45]

Another feature that is a must-have in today's vehicles is phone mirroring software, namely Apple Carplay and Android Auto. This enables the customer to have full integration of various navigation, messaging, social media and music apps in their smartphone with the vehicle's user interface and displayed on the vehicle multimedia screen. However, Aston Martin has integrated the vehicle's multimedia user interface into the customer's smartphone using a dedicated smartphone holder (Figure 2.4.4) in the new Aston Martin Vanquish; while the important and obligatory vehicle parameters are displayed on a dedicated screen behind the steering wheel. This is certainly the future; with smartphones that have all of the user's preferred music, apps and other softwares in sync with a connected vehicle for the vehicle to understand the user preferences and make suggestions during the time spent inside the proposed quadricycle.

The integration of vehicle multimedia software into smartphones is inevitable as smartphone adoption is at almost 100% according to a study [47] conducted in 2016 in India. It is interesting to note that smartphone usage time of over 50% of the study correspondents (mainly university students) was upto 8 hours per day.

The result of the previously mentioned study is important because, people who are used to operating apps and software in a superior computing device (like smartphones in the market) to the VCU (Vehicle Control Unit), the easier it would be for customers of the proposed quadricycle to operate its multimedia system and HVAC (Heating Ventilation and Air Conditioning) in their smartphones while also increasing profit margins to vehicle manufacturer.

Inorder to achieve this level of connectivity, it would require the manufacturer to have a dedicated smartphone holder with charging ports or charging capability and a high speed WiFi (Wireless Fidelity) connection - 802.11ac (WiFi protocol to operate in 5GHz bandwidth rather than 802.11n that operates in 2,4GHz) to the VCU. This would allow the user to seamlessly operate their smartphone and the vehicle functions like HVAC, Music, Navigation and Vehicle settings etc while also being ergonomically placed inside the vehicle as seen in Figure 2.3.1.

Figure 2.4.4: Aston Martin Vanquish prototype with factory smartphone holder [46]

C-V2X communication capability

India is on the verge of shifting to 5G communication protocol and the number of 4G users and the demand for faster internet speeds are driving the telecommunication companies to upgrade to 5G as fast as possible inorder to obtain more customer base so as to win the race to be India’s largest telecommunication / internet provider.

India is the world's second-largest internet market after China. But India also happens to be the largest untapped internet market in the globe and this is what makes it more irresistible for Silicon Valley companies. There's little doubt that the next billion internet users are going to come from India given that there are almost 900 million people in India without access to the internet. [48]

This situation is advantageous for the industry standard for vehicle communication technology - Cellular Vehicle-to-Everything (C-V2X) technology that is available today. The 4G and 5G based technology is designed to connect vehicles to each other, to roadside infrastructure, to pedestrians and cyclists, and to cloud-based services. C-V2X can be used in many different ways to improve road safety, while making more efficient use of transport networks and infrastructure [48]. For example, it can support:

1. **Collision avoidance**: In the future, each vehicle on the road could use C-V2X to broadcast its identity, position, speed and direction. An on-board computer could combine that data with that from other vehicles to build its own real-time map of the immediate surroundings and alert the driver to any potential collisions or accidents on the road.

2. **Platooning**: The formation of a convoy in which the vehicles are much closer together than which can be safely achieved with human drivers, making better use of road space, saving fuel and making the transport of goods easier.

3. **Cooperative & autonomous driving**: By sharing sensor data, vehicles can use C-V2X to work together to minimise the disruption caused by lane changes and sudden braking. Along with other sensors and communications systems, C-V2X will play an important role in enabling vehicles to become increasingly autonomous.

4. **Queue & hazard warning**: Roadside infrastructure can use C-V2X to warn vehicles of queues or road works ahead of them, so they can slow down smoothly and avoid hard braking. C-V2X can be used to extend a vehicle's electronic horizon, so it can detect hazards around a blind corner, obscured by fog or other obstructions, such as high vehicles or undulations in the landscape.

5. **Supporting the emergency services**: C-V2X can be used to warn road-users in advance about emergency vehicles en route to an incident so as to clear the path for them.

6. **Collecting road tolls**: designed to reduce congestion and the impact of motor transport on the environment through reduced emissions, and can also integrate FastTag [49] in India.

7. **Avoiding vulnerable road-users**: by detecting pedestrians and cyclists' smartphones, C-V2X can help vehicles to avoid other road users.

As an example for a C-V2X unit, one could look at the 5G telematics unit by Continental Engineering [50] which has a programmable OS (Operating System) for including various operating protocols to customise the functioning of various components in the device to meet the requirements of the manufacturer. Figure 2.4.5 below shows a typical 5G telematics module with its respective components, all of which could be programmed to function according to the software coded by the manufacturer.

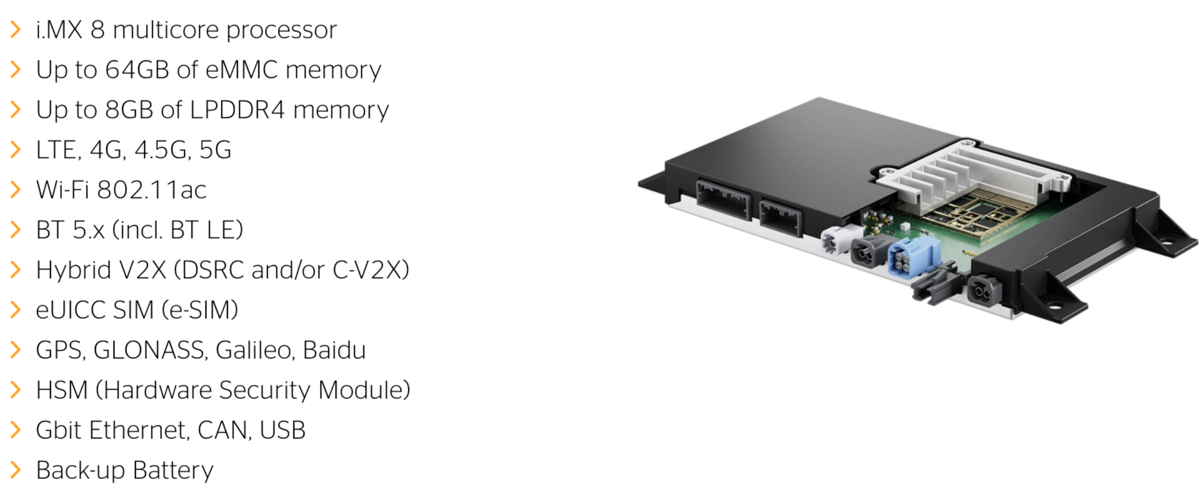


Figure 2.4.5: A 5G telematics unit with respective components [50]

Safety features

The proposed quadricycle would require the standard list of active and passive safety features like ABS (Anti-lock Braking System), ESP (Electronic Stability Program), Airbags and Parking sensors to meet the safety regulations of the Indian market. The ARAI (Automotive Research

Association of India) mandates ABS, Airbags and Parking sensors to be standard in all cars sold in the market.

1. ABS has been made mandatory for all new cars to be sold from April 2019. [52]

2. Driver-side airbag, speed warning system, seatbelt reminder for both driver and co-driver and rear parking sensors have to be part of standard features of a car from July 2019. [52]

And like in any other market, in India, the production ready prototype is homologated (if required), tested, validated and certified by the ARAI for introduction into the Indian market according to the existing crash and safety regulations prevalent. [78]

Sound synthesis

Sound synthesis is a relatively new development in the automobile sector, where sounds both inside and outside the cabin are engineered to either negate certain sounds or to enhance certain sounds both for safety and entertainment purposes.

Sound synthesis can include the following capabilities to an EV:

1. **External sound synthesis**

   EVs inherently are much more silent than gasoline cars. In some markets, it is mandatory for EVs to emit a sound inorder to warn pedestrians and cyclists about an approaching vehicle, especially in an urban environment. And various manufacturers have equipped their vehicles with interesting sounds to meet this requirement. [60]

   In a study [60], artificial engine sounds were generated using a sample based algorithm to generate engine sounds at various engine speeds for the purpose of being transmitted to either outside the vehicle inorder to meet the regulations. Some researchers have also recorded and used actual engine sounds to be used for this purpose in computer gaming and in real-life. [76]

2. **Active noise cancellation**

Similar to the external sound synthesis, the active noise cancellation records noise from outside and emits the same sound through the car speakers with a 180° phase shift to cancel out the noises inside the cabin. The practical application of this would allow vehicles to reduce bulk and weight and could make EVs more efficient. A cabin noise reduction over a broad frequency range of 30Hz-1kHz for automotive applications is possible and available in the market. [77]

3. **Interior sound synthesis**

Similar to the processes in exterior sound synthesis, sounds of various types of engines used in various types of cars can be recorded to be played back into the cabin of an electric car for pure entertainment purposes of the owner. This can be incorporated into the proposed quadricycle with parameters like throttle position and speed of the vehicle programmed to correspond to the pre-recorded engine and exhaust sounds of various other vehicles, just like in a computer game [76].

2.5. Desired vehicle attributes from survey

As a part of this thesis, a survey was created to understand the choices and opinions of a random demographic of people about vehicles and especially electric vehicles. The survey also gauges the interest of people towards the proposed quadricycle by showing them a similar design with explanation about some of the proposed features for the quadricycle. In this section, the results of the survey are analysed to interpret various choices and discuss the possible reasons for their choices.

Transportation choices

In order to classify the survey respondents into a certain economic level (in a very crude way), the age and type of transportation of their choice were asked. Respondents below the age of 25 years were considered to be on the first level of economic scale with either no income (dependents) or employed with basic pay who may be looking to buy their first vehicle (most probably a two-wheeler). The respondents between ages of 26 years and 35 years were considered to be in the high spending category either married with or without babies or single; and looking to buy their first four-wheeler or the proposed quadricycle (as a comfortable alternative to their current two-wheeler).

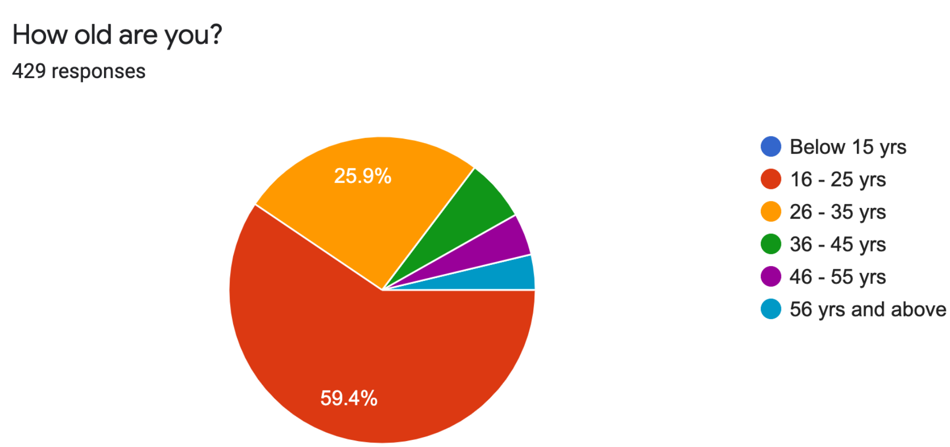


Figure 2.5.1: Survey results - age of respondents

The respondents between ages of 36 years and 45 years are considered to be married homeowners with teenage kids and have more than one vehicle (one large and another small) and maybe looking for another daily commute vehicle (either a two-wheeler or the proposed quadricycle); because the large vehicle was purchased as a status symbol which large and inefficient to commute with in the city and now both the husband and wife wants independent mode of private transport.

The respondents between the ages of 46 years and 55 years are considered to be parents of kids approaching 16 years old or older and maybe considering buying their kid their first vehicle for their daily commute. While respondents who are 56 years or older are considered to be at the highest economic level but are more likely to either love or hate the proposed quadricycle as people who are older generally do not like major changes in life.

It is also important to note that the majority of the survey respondents have a private mode of transport (over 73%) as shown in Figure 2.5.2 hence why there is no mention of public transport or other modes of transport in the above assumptions.

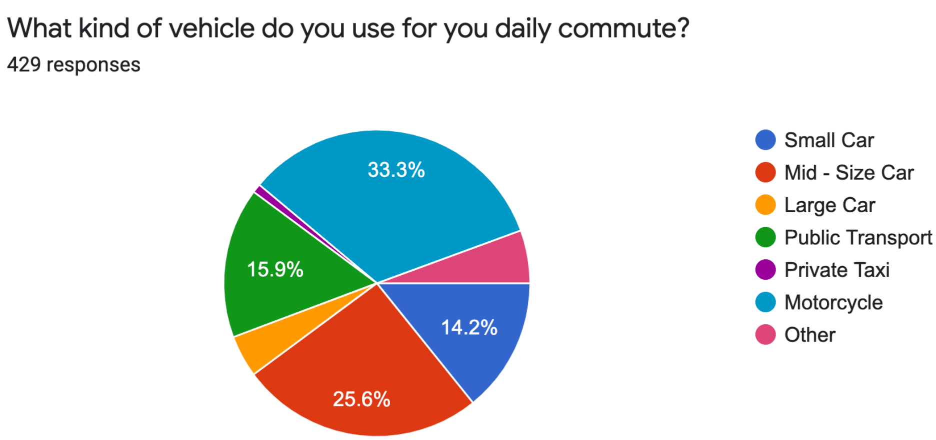


Figure 2.5.2: Survey results - type of vehicle for commute

Electric vehicle ownership prospects

To understand the vehicle ownership and vehicle ownership aspirations of the respondents, it was asked if they own a vehicle or if they plan on owning a vehicle in the next 5 years. Ownership prospects in 5 years were asked because the legal driving age in India is 20 years in some states; and the minimum age taken into consideration for the survey is 16 years. It was interesting to note that 89,8% of the respondents answered affirmatively.

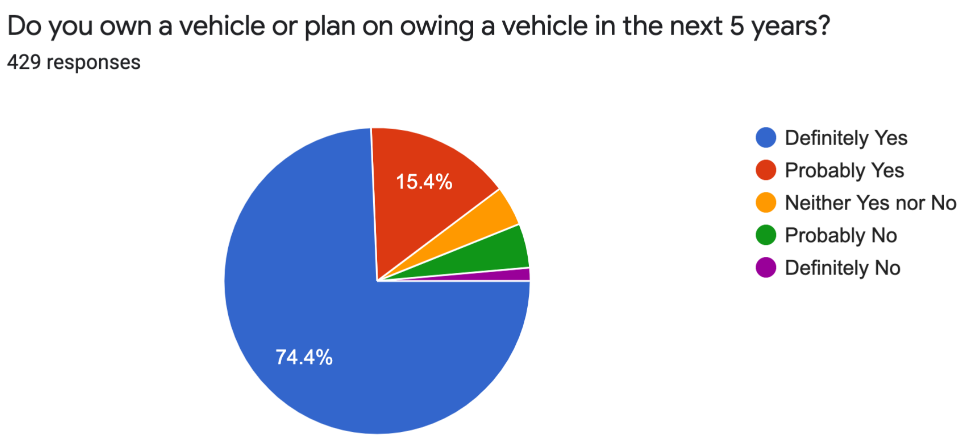


Figure 2.5.3: Survey results - vehicle ownership prospects

While 72% of the respondents answered affirmatively to ownership prospects of an electric vehicle, a relatively lesser percentage, nevertheless a significantly high percentage to say that electric vehicles would be accepted positively.

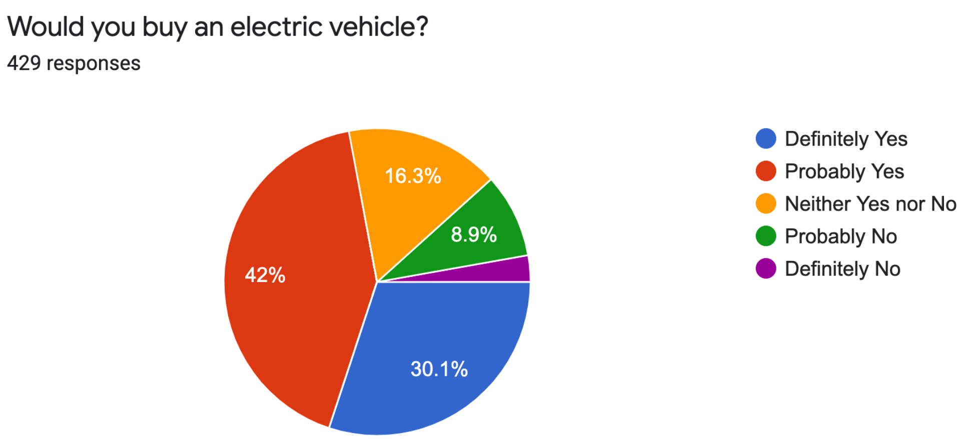


Figure 2.5.4: Survey results - electric vehicle ownership prospects

Reasons for buying an EV

Of the 72% of respondents who answered affirmatively towards owning or buying an electric car, the reasons for their choice were enquired and the following responses (as seen in Figure 2.5.5) were recorded. It was interesting to note that most of the respondents want to buy an EV for its lower emissions; while the least number of respondents were interested in the brand of the vehicle, which is a positive result for the proposed quadricycle, given that it would be marketed under a new brand name.

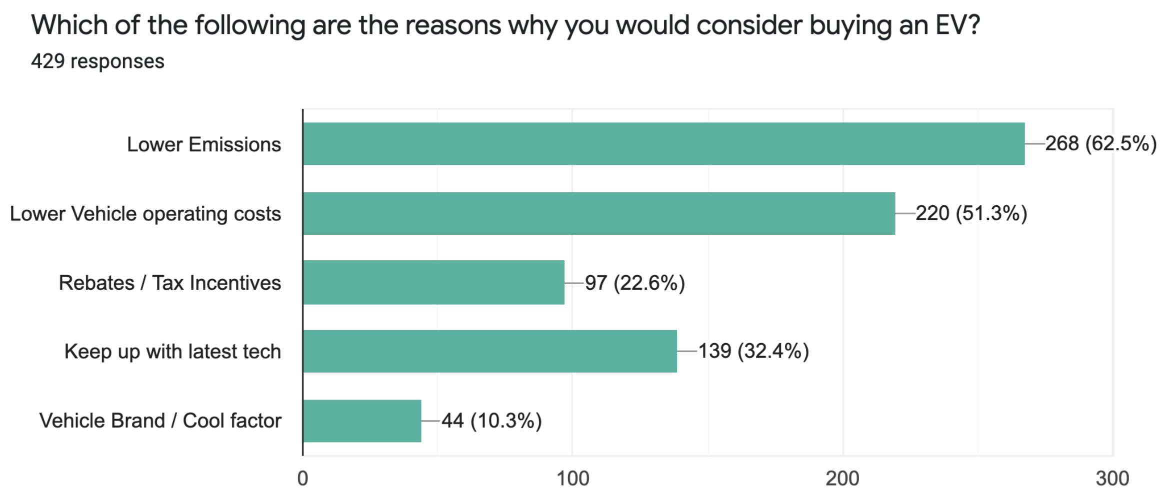


Figure 2.5.5: Survey results - reasons to consider an EV

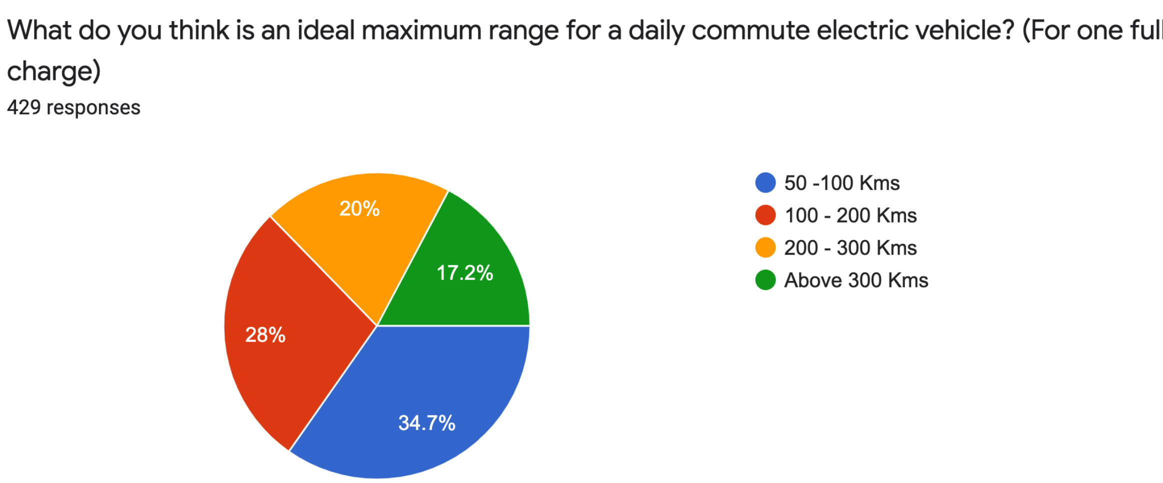


Figure 2.5.6: Survey results - ideal maximum range of an EV

The expected maximum range from the proposed quadricycle was enquired and Figure 2.5.6 shows the results. Even though the most number of people (34,7%) chose a maximum range of between 50 kms - 100 kms for a full charge, the option of 100 kms - 200 kms for a full charge was a close second at 28% and also a realistic target, hence 200 kms was chosen as a target maximum range for the quadricycle.

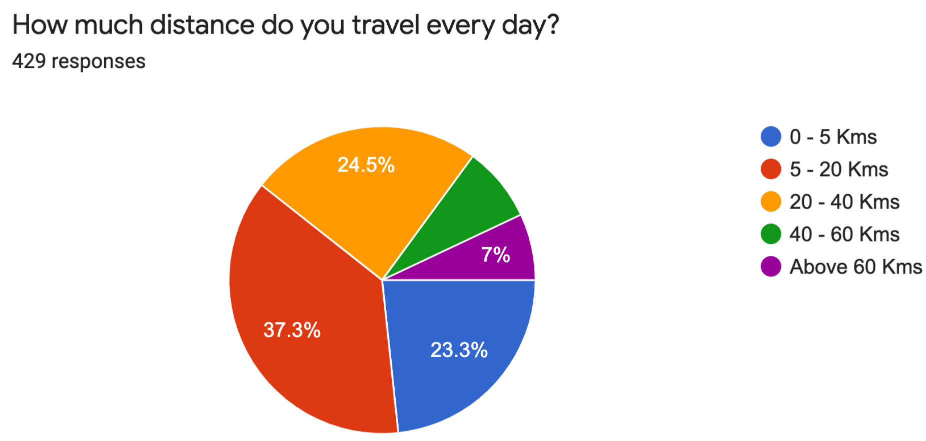


Figure 2.5.7: Survey results - distance travelled per day

Taking into account the results from Figure 2.5.7, the average distance travelled per day is considered at a maximum of 20 kms for 6 days in a week, the battery range loss is estimated at 5% per week and also considering the range anxiety of the user, the user will end with 30 - 35% battery remaining at the end of the week before another full charge. Thus, the 200 kms maximum range for the proposed quadricycle is a more realistic range target from usability perspective. Also since the proposed quadricycle is light weight with a target weight of less than 450 kgs (excluding batteries), this range target is achievable with a lower capacity battery pack when compared to a regular compact electric car at about 1.500 kgs (including batteries).

The respondents were also asked about the desired attributes while choosing a vehicle; and the safety of the vehicle was the most chosen attribute followed closely by Performance and Efficiency of the vehicle. Figure 2.5.8 shows the list of attributes and each of their scores from the survey. On a positive note for the proposed quadricycle, the brand of the vehicle was the least chosen attribute from the list of options, hence with a good marketing strategy a new brand could succeed in the Indian market.

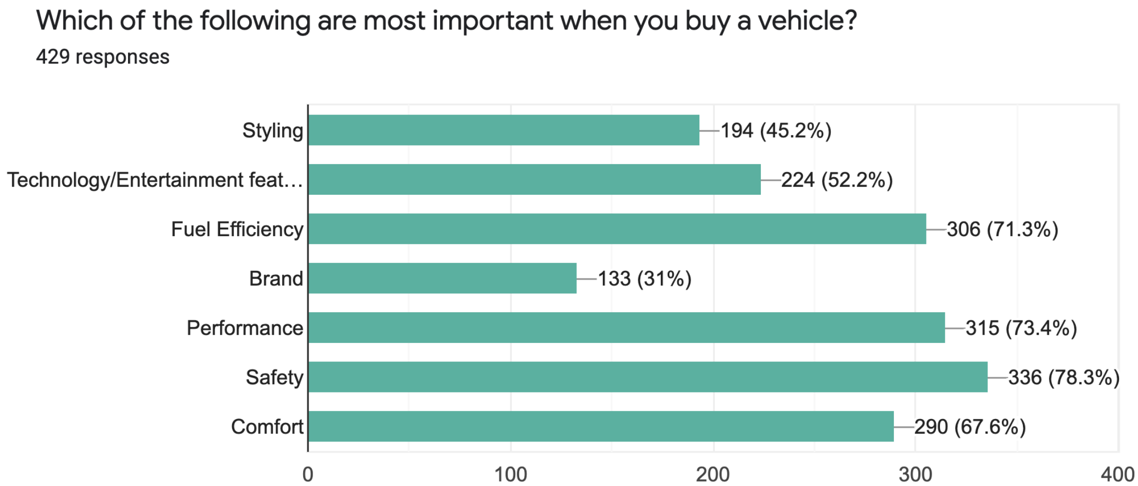


Figure 2.5.8: Survey results - important attributes of a vehicle

3. Cost estimation of quadricycle

The pricing of the proposed quadricycle is very important in determining the success of any product in the market, especially in India, where this product will be sold in a non-existent segment of vehicles till date. This chapter of the thesis aims to estimate a target price for the proposed quadricycle on the basis of a survey held, from the foreseeable competition in the market and compare the price obtained to the cost estimation from the bill of materials available from a comparable vehicle and from related research papers.

3.1. Price estimation from market

Compact cars in India

Compact cars, majorly hatchbacks, contribute to about 50% of passenger car sales in India. Figure 3.1.1 shows the sales data of both two-wheelers and four-wheelers in 2019, and Figure 3.1.2 shows the compact car sales in India. This trend has remained in the market for a long time as seen in Figure 3.1.2 with data from 2009 to 2019. The sales data for 2020 was overlooked because of the effects of COVID-19 pandemic, which is discussed in further detail in one of the following chapters of this thesis.

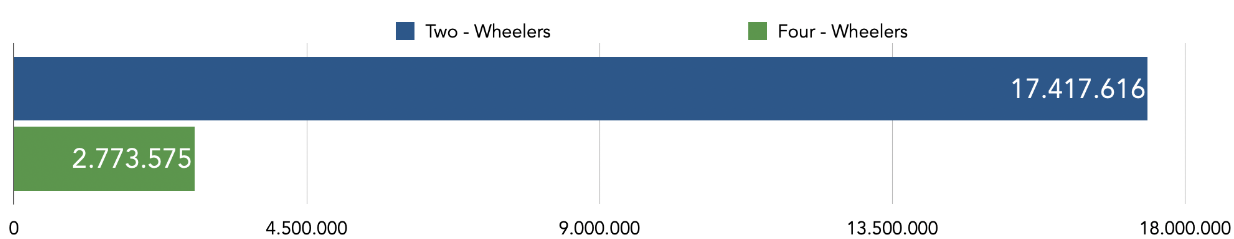


Figure 3.1.1: Two - wheeler and Four - wheeler sales data [9]

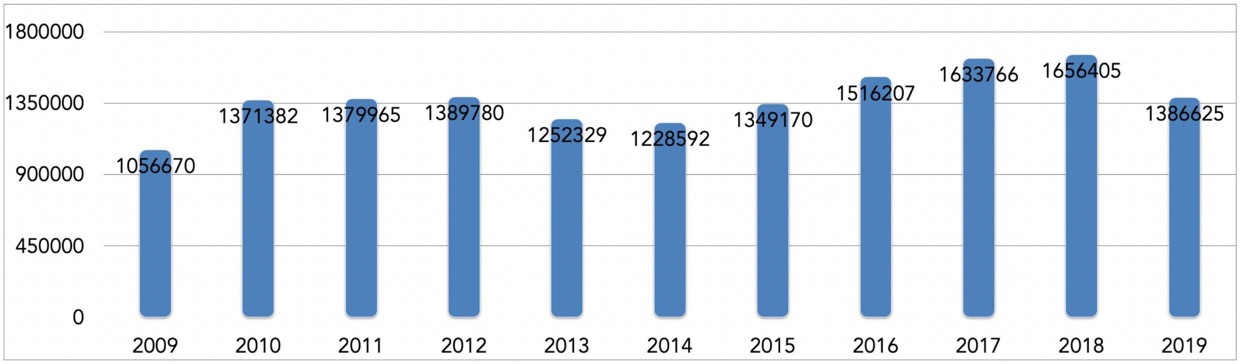


Figure 3.1.2: Compact car sales numbers 2009 -2019

Figure 3.1.2 shows the total number of sales in compact car numbers from a confidential source inside a major auto manufacturer in India. The data suggests a very high number of sales at 1.386.625 units, which is half of the total car sales in India that stood at 2.773.575 units for 2019. The compact car segment is the most competitive segment in the four-wheeler market and the sales numbers are very important to understand various customer preferences and market demand for various cars.

Table 3.1.1 shows the list of the 9 top selling compact cars in India with their prices for lower variant and higher variant shown in Indian Rupee. The average price of all the vehicles was calculated at €8.140. (Conversion rate taken at 1€ = ₹ 86,5)

SNo	Company	Model	Low Variant	High Variant	Average
1	Suzuki	Swift	569.000,00 ₹	1.015.000,00 ₹	792.000,00 ₹
2	Suzuki	Alto	328.000,00 ₹	456.000,00 ₹	392.000,00 ₹
3	Suzuki	Baleno	667.000,00 ₹	917.000,00 ₹	792.000,00 ₹
4	Suzuki	Brezza	874.000,00 ₹	1.255.000,00 ₹	1.064.500,00 ₹
5	Hyundai	Grand i10	711.000,00 ₹	873.000,00 ₹	792.000,00 ₹
6	Tata	Tiago	597.000,00 ₹	771.000,00 ₹	684.000,00 ₹
7	Suzuki	S-Presso	405.000,00 ₹	493.000,00 ₹	449.000,00 ₹
8	Hyundai	i20	612.000,00 ₹	1.064.000,00 ₹	838.000,00 ₹
9	Suzuki	Celerio	471.000,00 ₹	594.000,00 ₹	532.500,00 ₹
	Total Average			**8.138,73 €**	**704.000,00 ₹**

Table 3.1.1: Top Selling Compact Cars in India 2019 - Prices [26]

Premium motorbike prices in India

Motorbikes 250cc and above are considered as premium motorbikes in India because of their relatively higher price and exclusivity. The premium motorbike segment has seen significant growth in the previous years, since 2010 many international brands have taken the opportunity to introduce their latest products in the Indian market with great success. This segment is forecasted to have a good growth rate in the coming years with growing passion for two-wheelers and the need for exclusivity among customers.

Inorder to understand the prices of the premium motorbikes, 9 motorbikes were considered according to their sales numbers. Table 3.1.2 shows that the average price of the 9 top selling premium motorbikes in India is approximately €4.660. There are however motorbikes with higher prices in the market, however sales numbers are significantly lesser.

SNo	Company	Model	Low Variant	High Variant	Average
1	Kawasaki	Ninja 300	365.000,00 ₹		365.000,00 ₹
2	Yamaha	R3	326.000,00 ₹		326.000,00 ₹
3	Harley Davidson	Street 750	491.000,00 ₹	518.000,00 ₹	504.500,00 ₹
4	Benelli	TNT 300	303.000,00 ₹		303.000,00 ₹
5	Kawasaki	ER-6n	496.000,00 ₹		496.000,00 ₹
6	Kawasaki	Z250	311.000,00 ₹		311.000,00 ₹
7	Kawasaki	Ninja 650	537.000,00 ₹		537.000,00 ₹
8	KTM	RC390	225.000,00 ₹		225.000,00 ₹
9	Benelli	TNT 600i	542.000,00 ₹	573.000,00 ₹	557.500,00 ₹
	Total Average			**4.656,39 €**	**402.777,78 ₹**

Table 3.1.2: Premium motorbikes in India 2019 - Prices [26]

Four-wheeler EV prices in India

The four-wheeler EV market was initiated in India with the introduction of the REVA back in the early 2000s [79]. It was only after almost 2 decades that the segment saw another new entrant from a different brand (Hyundai Kona launched in 2019). Since then, more EVs have been introduced in the market by various brands at various price levels. It is not practical to estimate an average price by comparing all the EVs due to a big variation in prices, however the Table 3.1.3 shows the prices of various EVs in the market ranging from luxury cars to affordable vehicles.

SNo.	Company	Model	Low Variant	High Variant	Average Price	Price in Euros
1	Mercedes-Benz	EQC	12.480.000,00 ₹		12.480.000,00 ₹	**144.277,46 €**
2	Hyundai	Kona Electric	2.850.000,00 ₹	2.872.800,00 ₹	2.850.000,00 ₹	**32.947,98 €**
3	MG	ZS EV	2.518.800,00 ₹	2.901.600,00 ₹	2.518.800,00 ₹	**29.119,08 €**
4	Tata	Nexon EV	1.678.800,00 ₹	1.966.800,00 ₹	1.678.800,00 ₹	**19.408,09 €**
5	Tata	Tigor EV	1.437.000,00 ₹	1.485.000,00 ₹	1.437.000,00 ₹	**16.612,72 €**

Table 3.1.3: Four-wheeler EV prices in India 2020 [26]

Two-wheeler EV prices in India

The two-wheeler EV market has shown tremendous growth in the previous years and all the sales projections imply a steady growth in this segment for the coming years [20]. Like the four-wheeler EV market in India, the two-wheeler EV market has a variety of products in different price ranges, but the products listed in Table 3.1.4 are the entry level motorbikes with higher sales numbers among two-wheeler EVs.

SN o.	Company	Model	Low Variant	High Variant	Average Price	Price in Euros
1	Bajaj	Chetak	100.000,00 ₹	115.000,00 ₹	107.500,00 ₹	**1.242,77 €**
2	Revolt	RV400	103.000,00 ₹	118.000,00 ₹	110.500,00 ₹	**1.277,46 €**
3	Hero Electric	Optima LA	44.900,00 ₹		44.900,00 ₹	**519,08 €**
4	Ather	450X	142.000,00 ₹	161.000,00 ₹	151.500,00 ₹	**1.751,45 €**
5	TVS	iQube Electric	108.000,00 ₹		108.000,00 ₹	**1.248,55 €**
6	Kabira Mobility	KM 3000	126.000,00 ₹		126.000,00 ₹	**1.456,65 €**
7	Hero	Electric Flash	39.990,00 ₹	52.990,00 ₹	46.490,00 ₹	**537,46 €**
8	Kabira Mobility	KM 4000	136.000,00 ₹		136.000,00 ₹	**1.572,25 €**
9	PURE EV	Epluto	71.900,00 ₹		71.900,00 ₹	**831,21 €**
10	Joy e-bike	Monster	98.990,00 ₹		98.990,00 ₹	**1.144,39 €**

Table 3.1.4: Two-wheeler EV prices in India 2020 [26]

This exercise of comparing the prices of various four-wheelers and two-wheelers with both IC engines and electric motors is to understand how the majority of products in the market stand from the perspective of pricing. In order to have good sales numbers for the proposed quadricycle, it is important to price it between the average asking prices of premium two-wheelers and compact four-wheelers because the proposed quadricycle is supposed to be a "better motorbike" for daily commute with the comfort and safety features of a four-wheeler. So based on the market competition, the recommended price for the proposed quadricycle should be between €4.500 and €8.100 inorder to achieve significant market sales.

3.2. Price estimation from survey results

Inorder to understand the market for the proposed quadricycle and preferences of people, a survey was curated for a random group of more than 425 people from various locations in India. The survey had questions to understand the age demographic of the respondent, current transport preferences, vehicle ownership prospect and preferred mode of city commute from three choices including the proposed quadricycle.

The majority of the survey respondents were in the age group of 16-25 years (59,4%) followed by 26-35 years (25,9%). This is a good result for the survey [Figure 3.2.1], as the proposed quadricycle is targeted for sale to a first time vehicle user or a second/third car buyer who wants a city car.

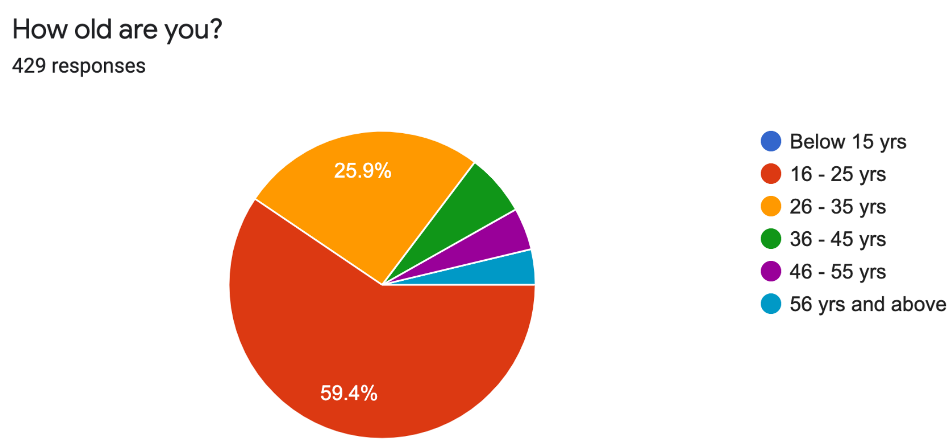


Figure 3.2.1: Survey results - Age group of survey participants

Also, to understand the expectations of the survey respondents, a question was asked about how much each of them would spend on a small vehicle for daily commuting. It was interesting to note that around 35% of the survey respondents chose the price range of €5.750 - €8.600 and around 40% of the respondents chose the expected price to be below €5.750. Both of these options overlap with the price range of between €4.500 and €8.100 that was proposed after analysing the 9 top selling cars and motorbikes in the market and then taking their average prices respectively in the previous section 3.1.

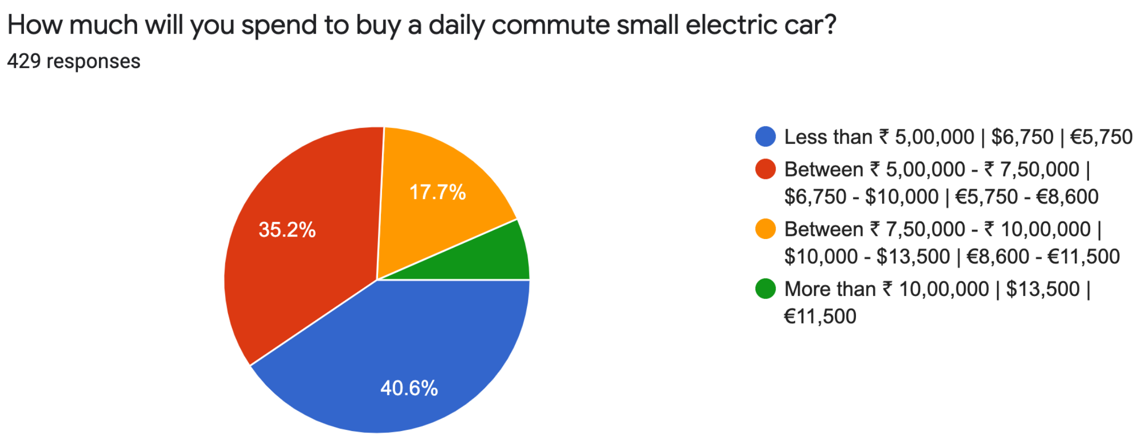


Figure 3.2.2: Survey results - Price choice of survey respondents

This result from the survey could allow us to conclude that the price analysis from section 3.1. is a step in the right direction for deciding a price for the proposed quadricycle. The survey result is also in line with the total vehicle sales in India, with a majority of the total four-wheeler sales being from compact cars and affordable cars.

Other details for cost estimation

In addition to the approximate amount that the survey respondents were willing to spend on a ‘small electric car’, their mindset regarding the product placement of electric vehicles were gauged to determine various marketing strategies.

The survey respondents were asked if they would pay extra for an electric vehicle that is similar in size and features to a gasoline car. And the percentage of survey respondents who answered affirmatively were at 63% and almost 15% were not sure if they would or would not pay extra. This leads one to determine that EVs have a higher price in the mind of the survey respondents and a manufacturer could justify the extra cost of batteries to a prospective customer.

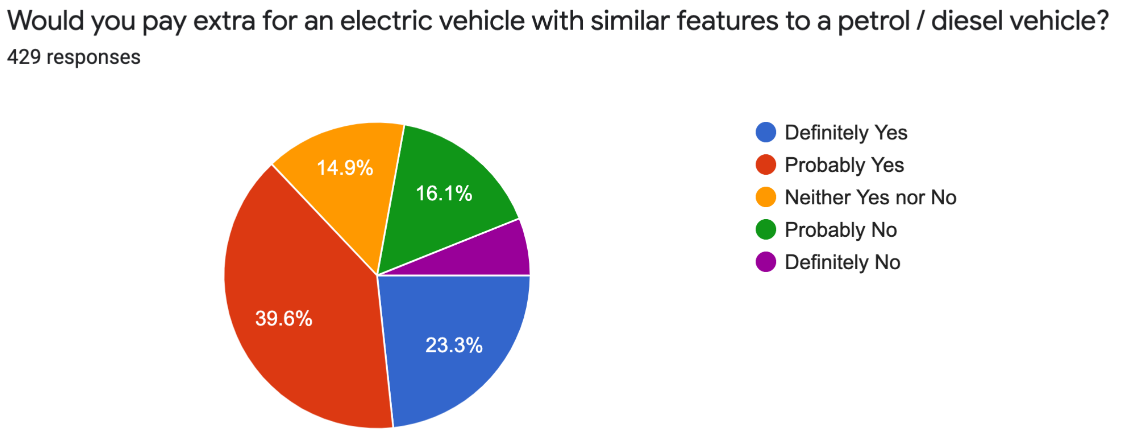


Figure 3.2.3: Survey results - pay extra price for EV

The survey respondents were also asked how much extra price they would pay for an EV of similar features and size to a gasoline car and only very few respondents answered negatively. Even though 45% of the respondents would pay only less than €1.150, an equally significant 39% would pay between €1.150 and €2.300 extra for an EV than a comparable gasoline car.

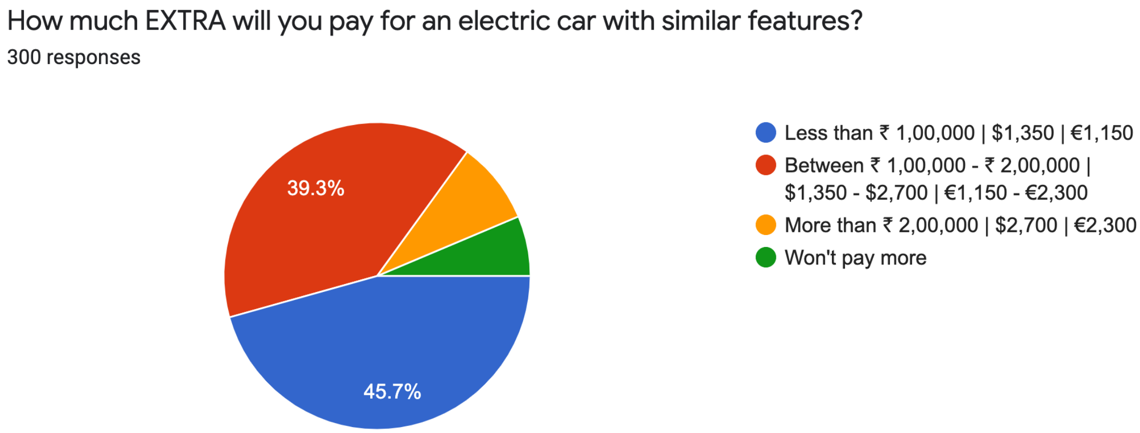


Figure 3.2.4: Survey results - how much extra pay for EV

3.3. Cost estimation from bill of materials

In this method of cost estimation, the basic materials and parts used in a vehicle were listed to understand the various modules in a vehicle and their costs in the market. Then these costs were calculated for markups and then added to engineering costs, factory setup costs, R&D costs and other costs like marketing, SG&A etc

Cost of various parts of reference vehicle

Inorder to understand a basic outline of most of the parts that would be used in the proposed quadricycle, an entry level compact car (a Hyundai Eon) was considered. Then the parts associated with the reference vehicle were analysed and documented from a spare parts catalogue [80] along with their respective prices.

SNo	Module	Component	Types	Quantity	Unit Cost (INR)	Sub Total (INR)	Total (INR)
1	Front Suspension System	Bushes	Bush - Lateral Rod	2	366 ₹	732 ₹	50.743 ₹
			Bush - Front Lower Arm	2	124 ₹	248 ₹	
			Bush - General	4	216 ₹	864 ₹	
			Bush - Control Arm	4	285 ₹	1.140 ₹	
			Bush - Control Arm Mount	4	501 ₹	2.004 ₹	
			Bush - Trailing Arm	4	541 ₹	2.164 ₹	
			Bush - Lateral Rod	2	1.462 ₹	2.924 ₹	
		Cover	Suspension cover	4	100 ₹	400 ₹	
		Axle	Torsion Axle	1	6.275 ₹	6.275 ₹	
			Torsion Axle parts	1	100 ₹	100 ₹	
		Tie Rod	Joint Assy - Inner Ball	1	700 ₹	700 ₹	

		Shock Absorber	Strut Assy	4	1.200 ₹	4.800 ₹	
			Bearing	4	900 ₹	3.600 ₹	
			Boot	4	100 ₹	400 ₹	
			Bump Stop	4	650 ₹	2.600 ₹	
			Insulator Assy - Strut	4	2.400 ₹	9.600 ₹	
			Cover - Insulator Dust	4	160 ₹	640 ₹	
			Pads - Front Spring	2	540 ₹	1.080 ₹	
			Pads - Rear Spring	2	140 ₹	280 ₹	
			Front Strut Mount	2	400 ₹	800 ₹	
		Spring	Front Coil Spring	2	461 ₹	922 ₹	
			Rear Coil Spring	2	835 ₹	1.670 ₹	
		Front Control Arm	Arm	2	700 ₹	1.400 ₹	
			Ball Joint Assembly	2	400 ₹	800 ₹	
			Front Stabiliser bar assembly	1	2.800 ₹	2.800 ₹	
			Fasteners		1.000 ₹	1.000 ₹	
			Bushes	4	50 ₹	200 ₹	
			Plate Assembly	2	300 ₹	600 ₹	
2	Rear Suspension System	Spring & Strut	Washer Spring	2	10 ₹	20 ₹	5.800 ₹
			Shock Absorber Assembly	2	1.050 ₹	2.100 ₹	
			Bolt	4	95 ₹	380 ₹	
			Rubber Bumper	2	670 ₹	1.340 ₹	
			Rear Spring Pad	2	140 ₹	280 ₹	
			Spring	2	840 ₹	1.680 ₹	
		Control Arm	Torsion Axle Assembly	1	6.300 ₹	6.300 ₹	8.240 ₹

			Nuts, Clips and other	6	15 ₹	90 ₹	
			Bush - Trailing Arm	2	545 ₹	1.090 ₹	
			Flange Nut	1	65 ₹	65 ₹	
			Rod Assembly	1	545 ₹	545 ₹	
			Bolt Lateral Rod	1	150 ₹	150 ₹	
3	Brake System	Brake Fluid Line	Bolts and Washers	4	25 ₹	100 ₹	6.831 ₹
			Nut Flange	1	15 ₹	15 ₹	
			Tube - Master Cylinder to Brake	2	140 ₹	280 ₹	
			Hose to Front	2	495 ₹	990 ₹	
			Tube - Connector to Rear	2	1.963 ₹	3.926 ₹	
			Hose to Rear	2	410 ₹	820 ₹	
			Tubes	4	125 ₹	500 ₹	
			Clips	4	50 ₹	200 ₹	
		Master Cylinder & Booster	Brake Master Cylinder Assembly	1	2.100 ₹	2.100 ₹	9.410 ₹
			Reservoir	1	460 ₹	460 ₹	
			Nuts, Clips and other		1.000 ₹	1.000 ₹	
			Piston Assembly - Secondary	1	450 ₹	450 ₹	
			Piston Assembly - Primary	1	450 ₹	450 ₹	
			Valves	2	750 ₹	1.500 ₹	
			Brake Booster Assembly	1	3.050 ₹	3.050 ₹	
			Hose Assembly - Brake Booster	1	400 ₹	400 ₹	

		Front Wheel Brake	Washer Spring	4	15 ₹	60 ₹	15.440 ₹
			Brake Pad Kit	1	1.075 ₹	1.075 ₹	
			Brake Assembly	2	3.055 ₹	6.110 ₹	
			Piston	2	405 ₹	810 ₹	
			Seal piston	2	35 ₹	70 ₹	
			Boot	2	20 ₹	40 ₹	
			Bleed Screw	2	35 ₹	70 ₹	
			Pad Kit	1	1.400 ₹	1.400 ₹	
			Spring Pad	1	75 ₹	75 ₹	
			Caliper bolt	4	90 ₹	360 ₹	
			Rod Assembly	2	180 ₹	360 ₹	
			Bolt Guide Rod	2	20 ₹	40 ₹	
			Caliper Kit	2	2.300 ₹	4.600 ₹	
			Bleed Screw Cap	2	10 ₹	20 ₹	
			Fixed pin	2	80 ₹	160 ₹	
			Sleeve	2	95 ₹	190 ₹	
		Rear Wheel Brake	Brake Assembly	2	2.400 ₹	4.800 ₹	9.600 ₹
			Drum Brake	2	1.800 ₹	3.600 ₹	
			Bolt and washers	24	50 ₹	1.200 ₹	
		Parking Brake	Lever Assembly	1	650 ₹	650 ₹	2.425 ₹
			Cable Assembly	2	575 ₹	1.150 ₹	
			Bracket	1	75 ₹	75 ₹	
			Switch Assembly	1	250 ₹	250 ₹	
			Bolts and Washers	20	15 ₹	300 ₹	
4	Axles	Front Axle	Disc Front	2	950 ₹	1.900 ₹	8.770 ₹
			Knuckle Front	2	1.500 ₹	3.000 ₹	
			Wheel Bearing	2	720 ₹	1.440 ₹	
			Hub Assembly	2	930 ₹	1.860 ₹	

			Dust Cover	2	160 ₹	320 ₹	
			Fasteners & others		250 ₹	250 ₹	
		Rear Axle	Snap Ring	2	35 ₹	70 ₹	9.100 ₹
			Wheel Bearing	2	1.550 ₹	3.100 ₹	
			Wheel Hub Cap	2	95 ₹	190 ₹	
			Hub Bolt	8	35 ₹	280 ₹	
			Pinion Lock Nut	2	525 ₹	1.050 ₹	
			Drum Brake	2	2.205 ₹	4.410 ₹	
5	Wheels	Wheel Assembly	Steel Wheel Assembly	4	860 ₹	3.440 ₹	9.400 ₹
			Hub nut	16	150 ₹	2.400 ₹	
			Wheel Cap Assembly	4	750 ₹	3.000 ₹	
			Tyre Valves	4	140 ₹	560 ₹	
6	HVAC Assembly	HAVC	HVAC Unit + Control Panel	1	11.665 ₹	11.665 ₹	28.580 ₹
		Condenser	Condenser core	1	3.470 ₹	3.470 ₹	
			Condenser Shroud	1	1.800 ₹	1.800 ₹	
			Condenser Seals	4	215 ₹	860 ₹	
			Flaps	1	400 ₹	400 ₹	
			Condenser with Fan + Seal	1	5.545 ₹	5.545 ₹	
		Evaporator	Evaporator Coil	1	4.840 ₹	4.840 ₹	
7	Steering System	Power Steering	Gear Assembly	1	6.000 ₹	6.000 ₹	31.370 ₹
			Nut	2	25 ₹	50 ₹	
			Bolt	2	60 ₹	120 ₹	
			Slotted Nut	2	110 ₹	220 ₹	
			Pin	2	15 ₹	30 ₹	
			Bolt	1	250 ₹	250 ₹	
			Column Assembly	1	12.400 ₹	12.400 ₹	

			Motor Assembly	1	4.800 ₹	4.800 ₹	
			Controller & Bracket Assembly	1	7.500 ₹	7.500 ₹	
		Steering Wheel	Wheel Assembly	1	3.100 ₹	3.100 ₹	6.450 ₹
			Screws	10	15 ₹	150 ₹	
			Upper Cover Assembly	1	3.200 ₹	3.200 ₹	
					Total	2.337 €	202.159 ₹
					Reducing retail and wholesale price markup of 40%	1.402 €	121.295 ₹

Table 3.3.1: Bill of materials from reference vehicle

Cost of other parts

These above-mentioned parts do not make up the whole parts list of the reference vehicle, but the list shows a detailed parts breakdown that would help to understand the parts requirement and approximate part costs in the proposed quadricycle. In addition to the above-mentioned parts, it is required to estimate the cost of the following components from various research papers, scientific articles and market prices. [81]

SNo.	Module	Component	Estimated Cost (INR)
1	Drivetrain	Motor + Gearbox	₹ 16.220 [1]
		Battery pack + ancillaries	₹ 178.500 [2]
		Inverter system	₹ 10.000 [3]
2	Exterior	Glass + Mirrors	₹ 5.000 [4]
		Lights	₹ 12.110 [5]
		Wipers	₹ 2.600 [6]
		BIW + Outer panels	₹ 72.660 [7]
3	Interior	Instrument Panel + claddings	₹ 2.500 [8]
		Infotainment + Instrument cluster	₹ 5.000 [9]

		Seat	₹ 4.325 [10]
		Airbag	₹ 1.750 [11]
		Safety belts	₹ 3.000 [12]
4	Electrical Systems	Interior Lights	₹ 500 [13]
		Wiring + Low Voltage Electronics	₹ 53.630 [14]
		ABS + ESP	₹ 12.975 [15]
		Parking Sensors	₹ 5.000 [16]
	Total	€ 4.440	₹ 384.020

Table 3.3.2: Bill of materials from research papers

[1] Cost of the motor was calculated at €10/kW according to a research paper [81] and an additional 25% was added to estimate the cost of a single speed gearbox.
(Conversion rate was taken at 1 € = ₹ 86,5)

[2] Battery pack costs were calculated at $100/kW for a planned battery of 17 kWh capacity and then multiplied by the cell-to-pack cost ratio of 1.4 from a research paper [81].
(Conversion rate was calculated at 1 $ = ₹ 75)

[4] Rate of glass was taken at ₹250/sq.ft for a total area of 20 sq.ft of 4 mm toughened safety glass.

[5, 6] Estimated based on a research paper. [81]

[7] Cost of Body panels and BIW (Body in White) was estimated to be 40% of a compact car as the material used and related costs would be lesser than the reference car. [81] [83]

[8] Instrument panel costs were estimated from a spare parts webpage. [82]

[9] Infotainment and instrument cluster are considered to be one LCD display of 10 - 12 inches with touch screen functionality.

[10] Estimated based on a research paper. [84]

[11] Estimated based on a research paper. [81]

[12] Estimated from spare parts webpage after adjusting for 40% retail and wholesale margins. [85]

[13] Interior light costs were considered from webpage [86] after adjusting for 40% retail and wholesale margins of two lights.

[14] Estimated based on a research paper. The wiring harness estimate was lowered to €100 because of the vehicle being smaller. [81]

[15] Estimated based on a research paper. [84]

[16] Estimated from spare parts webpage after adjusting for 40% retail and wholesale margins. [87]

Considering the estimated costs derived from both reference papers and reference vehicles, we obtain a total of €5.841,79 including the R&D costs of the components and modules as shown in Table 3.3.3 below.

SNo.	Details	Amount (INR)	Amount (Euro)
1	Amount from Bill of materials in various reference papers	384.020,00 ₹	4.439,54 €
2	Amount from Bill of materials of reference vehicle	121.295,00 ₹	1.402,25 €
	Total amount from Bill of materials	505.315,00 ₹	5.841,79 €

Table 3.3.3: Total cost from Bill of materials

Cost breakdown of proposed quadricycle

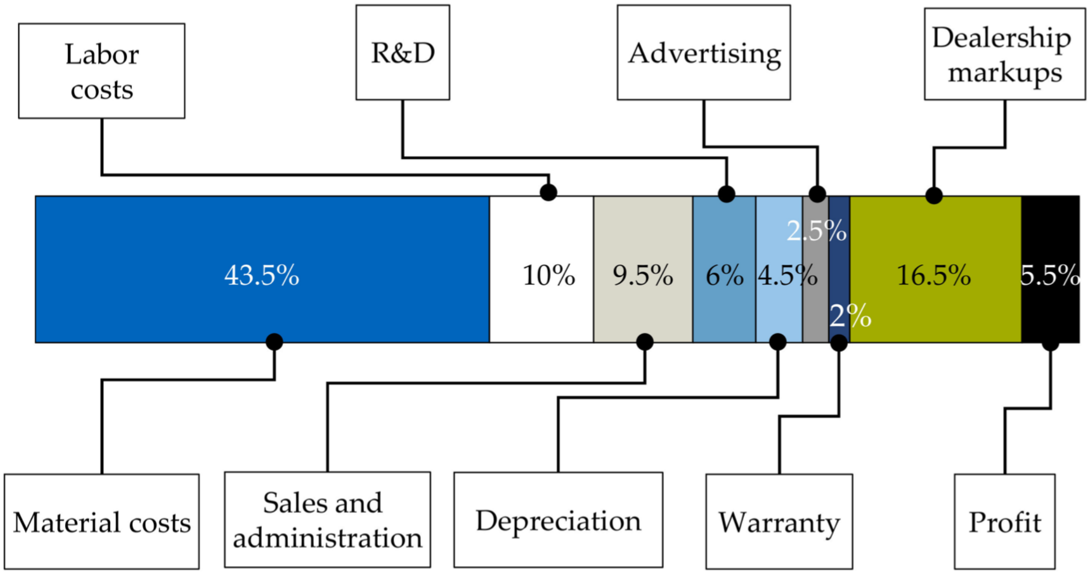


Figure 3.3.1: Cost breakdown for the net price of a new car [81]

According to a review published by the Technical University of Munich [81], the relevant parameters and costs of various modules and components of a modern electric vehicle were studied in order to enable manufacturers and researchers to develop and optimise BEVs.

The cost breakdown of a new EV is given in Figure 3.3.1 courtesy of the said review [81]. According to this cost breakdown, the current estimation from the bill of materials should include the following costs:

1. Material costs
2. R&D Costs

The above costs combined (€5.842) contribute to about 50% of the cost of a new vehicle. This would mean that the cost of the proposed quadricycle would be €11.690, based on the suggestion in the review [81]. But on further examination, one would understand that this cost breakdown is given for a mid-size car in the European market. Even though it is difficult to estimate the cost differences between the proposed quadricycle and a mid-size car, nonetheless the review is a good starting point for a technical estimation of various costs. The suggested costs were either used directly for cost estimation or adapted based on the requirements of the proposed quadricycle.

On initial analysis of the cost breakdown in Figure 3.3.1, if the vehicles were made to order, then the cost of depreciation (4,5%) could be avoided. Labour costs (10%) could be brought down from the total vehicle cost as the labour costs in India are lesser compared to Europe or USA and are very similar to China. Similarly, Sales and Administrative costs (9,5%) can also be brought down as skilled personnel are available at a much lower cost than Europe or the USA. If one were to reduce Labour costs and Sales & Administrative costs by half and if one were to produce the vehicle to order and thereby avoid depreciation, the total price of €11.690 can be reduced by 14,5% to €9.995.

Also, during the initial years of production to make the business easier and more cost effective, direct sales to customers will enable total profits to be reduced from 22% of the vehicle price (company profits + dealership margins) to 10% ; this will further reduce the cost of the proposed quadricycle to €8.592. This estimated amount is within the survey results for suggested price and in the vicinity of the cost analysis results obtained for the proposed quadricycle by comparing the market prices.

Even though this exercise is a very rough estimation of the suggested price for the proposed quadricycle, with careful planning and engineering, it stands to reason that costs can be brought down further. Other Costs involved in the making of this proposed quadricycle would be real estate costs and factory set up costs. The real estate costs would vary from region to region and in some cases, the state governments in order to support employment generation could even provide the land for free.

And for factory costs, a company in the UK claims to have developed a new method for production of vehicles that will allow investment costs to be cut by upto 80%. The new process is called the iStream manufacturing process and the company is called Gordon Murray Design [88][89]. If this is a suitable method of production for the proposed quadricycle, then the manufacturing process would be the ideal solution.

3.4. Suggested price for the proposed quadricycle

Several methods were used to estimate the price for the proposed quadricycle; based on the market price analysis results in Section 3.1. , the price suggestion from the marketing survey in Section 3.2. and the cost derived from the bill of materials in Section 3.3 , it would be possible to suggest a theoretical price.

SNo.	Details	Amount (INR)	Amount (Euro)
1	Suggested price based on Market analysis	Less than ₹ 700.650	Less than 8.100 €
2	Suggested price based on Survey results	Less than ₹ 743.900	Less than 8.600 €
3	Suggested price based on bill of materials	Less than ₹ 743.208	Less than 8.592 €

Table 3.4.1: Suggested prices for the proposed quadricycle from various methods

Table 3.4.1 shows the results from the various methods used to estimate the retail price of the proposed quadricycle. Based on the results, the ideal starting price of the proposed quadricycle should be less than €8.600 but above €5.600 inorder to have significant sales.

4. Business and Marketing Strategy

The business and marketing strategy plays a central role in the success of any new business venture. This chapter aims to explore a possible business strategy to help the proposed quadricycle gain more sales in the market.

Product image

The product should have the following characteristics highlighted in its image inorder to create a successful marketing strategy. Some of the following suggestions are based on marketing experiences of various brands in India. But one main focus for the marketing strategy would be to look into the reason for the failure of Tata Nano in India [92][93].

1. **Perceived value should be higher than cost**

   The proposed quadricycle has to be perceived as an expensive two-wheeler alternative rather than an entry level four-wheeler alternative. This is very important because most people in India tend to believe that cheap in price would mean cheap in quality. This was true in the case of Tata Nano, where the sales volume could not meet the projections and one of the reasons for this was that it was considered as the cheapest car in the world [93]. Also in the case of the Tata Nano, high expectations given to the public and inability to meet them were one of the reasons for its failure. The vehicle was uncomfortable on Indian road conditions with very small wheels (12 inch), then it was perceived as unsafe because of several instances of fire being reported.

2. **Second / Third car in the garage**

   The proposed quadricycle being a hybrid of a two-wheeler and a four-wheeler, it couldn't possibly be the primary vehicle in a garage and used only for urban commute and running errands. Even though the Tata Nano was marketed to the first time car buyer, the customers who bought it were not first time car buyers but “they’re people looking for a fun, trendy second car for running errands” and no real conversions were made from motorbike customers to car customers [93].

3. **European design & engineering with Indian manufacturing**

   European cars are considered to be premium vehicles in the Indian market mostly due to their broad design appeal with clear design evolution, sturdy build quality and premium price tag that creates a better brand value perception. These attributes make a brand more appealing or desirable for a customer, and any product that is appealing or desirable is easier to sell. While manufacturing in India would make the product more profitable for the company because of relatively lesser labour and energy costs in comparison to Europe or the USA.

   Also, it would work in favour of the product if it were to be sold internationally (Europe, USA) initially before being sold in India, to create the perception of being a global product and hence would be considered of higher quality. In the case of Tata Nano, it was later suggested that the product be sold internationally to create an image makeover for the product [95].

4. **A style statement**

   “Like apparel and lifestyle brands, a car is an extension of one’s perception. People buy cars which either match their personalities or those which provide them opportunities of being perceived as somebody they aspire to be. This becomes significant as consumers move up the value chain from small compact cars to midsize and upwards.” [94]

   Making the car a style statement will enable the company to sell the product with celebrity/personal endorsements and will also help in future collaborations with other lifestyle brands.

Marketing and Sales approach

The marketing and sales strategy will have to follow a top down method (selling more expensive variants or models first followed by less expensive ones), preferably with limited / special models that can help to run a pilot project to understand the real world usability and customer feedback before scaling up production. Apart from this, other suggested methods could be:

1. **Partnerships**

Partnership with Luxury and Fashion brands for special editions and limited editions will help prospective customers to associate with the new product's brand image in a better way [96]. One such possible partnership would be with a premium audio brand to provide an exceptionally good audio system for the car (eg: Bang & Olufsen audio partnerships [97]). There have been several other instances where luxury fashion brands have associated with automakers for special editions [96].

2. **Personalisation**

'Personalisation from the factory' is an option that is non-existent in the small size vehicle market. In today's world with high social media influence and focus on individualism, having an option to customise the colour of one's car would be a welcome addition, especially for a new manufacturer with low volume production when it would not be possible to install a fully automatic paint booth.

In the Indian market, in order to own a vehicle with custom colour from the factory, the buyer will need to opt for a brand like Porsche (or higher) with a starting price of at least 10-15 times the suggested retail price of the proposed quadricycle and also wait for more than 4-6 months. So the option to personalise a vehicle with paint to sample colours for both exterior and interior at an extra cost would be a first for a vehicle at the proposed price point and would be a well received addition in the market.

3. **Brand positioning**

Brands like Richard Mille [103] and Ferrari [104] follow a strategy where the retailers encourage customers to buy the entry level and less exclusive models in order to qualify for the purchase of the more exclusive and sought after models. This strategy helps the brand to position itself as a sought after brand with a loyal following while also increasing sales and interest in the brand.

If a new manufacturer were to use a similar strategy, where the prospective customer would have to submit proof of ownership (known as Registration Certificate or RC in India) of a luxury car in order to qualify for the purchase of the proposed quadricycle; it would help the new manufacturer to establish itself as a sought after brand on par with the luxury brands under consideration. And since vehicle ownership (especially of European luxury brands) still carries a certain level of pride in India, this would be a strategy that could benefit the manufacturer in the long run. This strategy would also encourage car traders to buy and resell the vehicles for a small profit while adding more sales for the manufacturer, because exclusivity is appreciated in general.

This exercise would also enable the new manufacturer to create a database of high net worth individuals that could be used later to advertise and sell more limited edition and luxury products from the manufacturer.

4. Direct-to-customer sales

Direct-to-customer online sales would allow the manufacturer to cut several overheads while focusing on the product. This strategy will also allow to increase profit margins and help keep better quality and customer experience control methods in check while avoiding time delays in starting initial sales of the product and maintaining the brand identity strictly. In fact, according to the survey that was conducted for the thesis (Figure 4.0.1) the results showed that more than 60% of people are willing to purchase their car online.

Having zero dealerships will eliminate heavy capital burden on retailers or the manufacturer (due to high real estate and building costs), while also having the flexibility of displaying the product in places like malls, airports and offices, thus reaching more prospective customers with less capital expenditure while increasing profit margins. This strategy will also enable the manufacturer to give the customer a different experience with home delivery of their new vehicle or even arrange for a delivery experience at a luxury hotel in their city (if needed).

Mercedes Benz India recently announced a change in their retail strategy with dealerships essentially acting as 'franchise partners' who are paid a commission for the sale while the customer buys the vehicle directly from Mercedes Benz India, thus eliminating a lot of risk for the retail partner. This strategy enables the company to have full control over pricing, offers and inventory across the country [98]; and in-turn making the pricing and offers standards for both online purchases and purchases from dealerships.

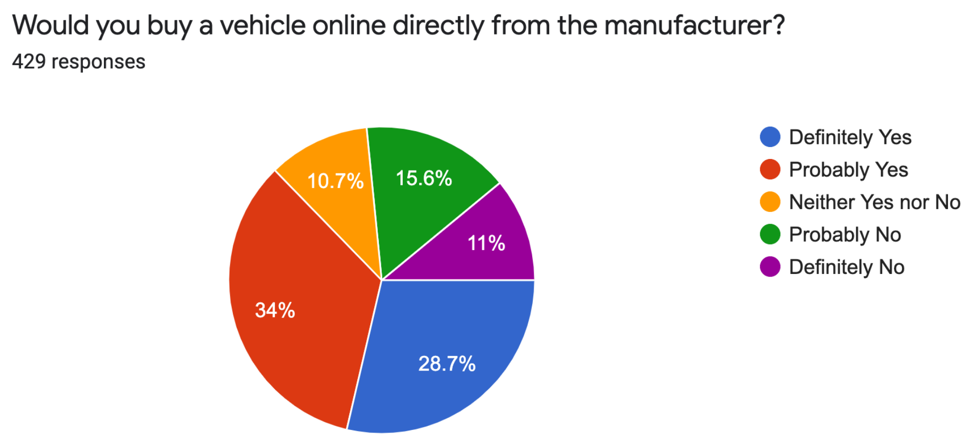


Figure 4.0.1: Survey results - online purchase

5. Mobile service units

Electric vehicles generally require less intensive routine general maintenance than an IC engine car and with over the air updates / fault rectification via a C-V2X communication device onboard, real estate and building costs of setting up a service center can be saved by opting for a mobile service team. Having a mobile service unit also enables the manufacturer to set up temporary service camps during after hours at a central or nearby shopping mall parking lot, and thus having the vehicle ready for the customer to use the next morning to reduce customer schedule interference.

While routine service and minor repairs can be carried out by the mobile team, all major repairs and diagnostics can be handled by the few strategically located service centers or workshops owned by the manufacturer beyond city limits to save on real estate costs. This also allows the manufacturer to have a well connected aftermarket team that can monitor defects and major faults easily and more efficiently while also recording the cases for faster R&D and product improvement.

6. Test-drives and product demonstration

With zero dealerships and floating display locations, a handful of demonstration vehicles would have to be spread within a city across various free parking lots that selected people can take for a test-drive using an app after registering their personal details (Mobile phone number, Aadhar number issued by UADAI, Driving License, RC of current vehicle etc.). Selection of customers for test-drive can be done by analysing the personal details given by the registered user, by partnership with banks (to filter people with certain types of accounts and credit history), by partnership with apps like CRED (credit card bill payment app that has a database of people with the best credit history in India)[102]; or even partnership with ride sharing apps like Uber or Ola that have people who need to get from one place to another and can use the demonstrator vehicle nearby their location to do so.

The customers taking test-drives will be greeted by an automated sales assistant (while also reducing sales person overheads) within the software of the car explaining the various features of the car; and after the sales pitch the customer can experience or use the vehicle for a limited duration and limited number of times for their respective purpose. And at the end of the test-drive, the other registered users near the location of the vehicle will receive a notification regarding the availability of a demonstrator that they can choose to accept or reject. Also, each car can be thoroughly cleaned, with the battery fully charged and relocated at night with a dedicated demonstrator service team.

7. Future opportunities

Quadricycles are legal to be driven by a 16 years or older person in Europe. Even though such a rule exists for certain types of motorbikes (usually not favoured by most young people), with lobbying and government support, this rule can be amended to include quadricycles to be legally driven by 16 year olds. Such an amendment would open a previously non-existent market of customers who are parents of 16 year olds who want a much safer transportation for their children than a e-scooter or motorbike to and from school. And since private mode of transport also helps to reduce risk of infection (COVID-19), sales to 16 year old drivers will become extremely significant.

In addition to the possibility of amendment to the rules, exemption from congestion charges that are likely to be incorporated into future city regulations (non-existent at present) would also work in favour of the proposed quadricycle.

Verdict from survey

As a final question in the survey, the respondents were asked if they would buy a 'micro car' for their daily commute and the results were positive for the proposed vehicle. Almost 57% of the respondents said that they would consider buying a 'micro car'. A little over 16% of the respondents were not sure whether to purchase a 'micro car' or not, and these respondents could probably be converted to potential customers of a 'micro car' with a good marketing strategy. Figure 4.0.2 shows the results from the survey as a pie chart with percentage distribution of the choices.

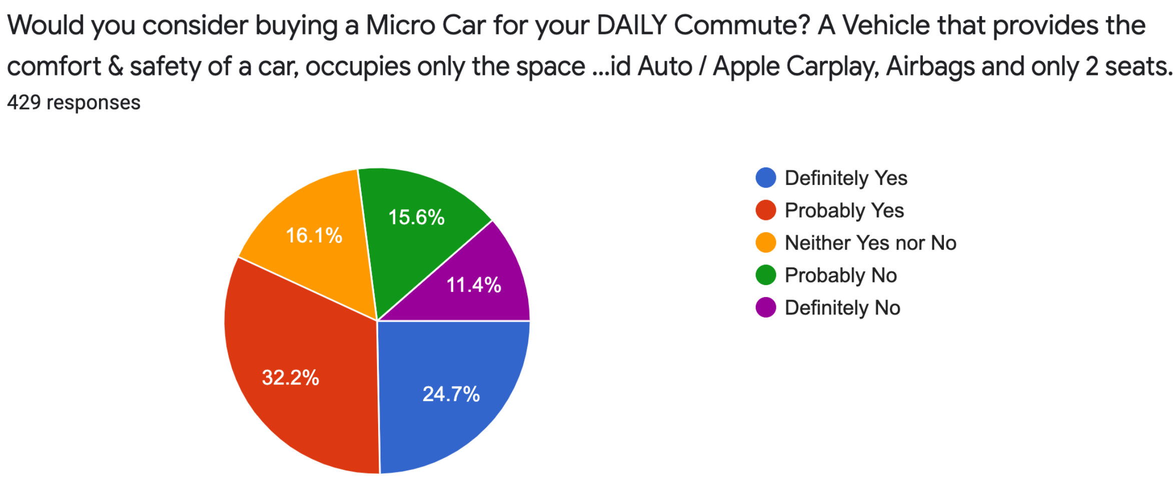


Figure 4.0.2: Survey results - micro car purchase decision

5. COVID-19 and its impact on the auto industry

The COVID-19 pandemic has adversely affected the way a lot of businesses work. Automobile factories were at a standstill during the initial months of lockdown with zero output. And the transportation and tourism industries were the most severely affected ones with constant lockdowns and restrictions for travel. But once travel restrictions were eased, the priorities of customers who want to travel changed, as shown in Figure 5.0.1. [90]

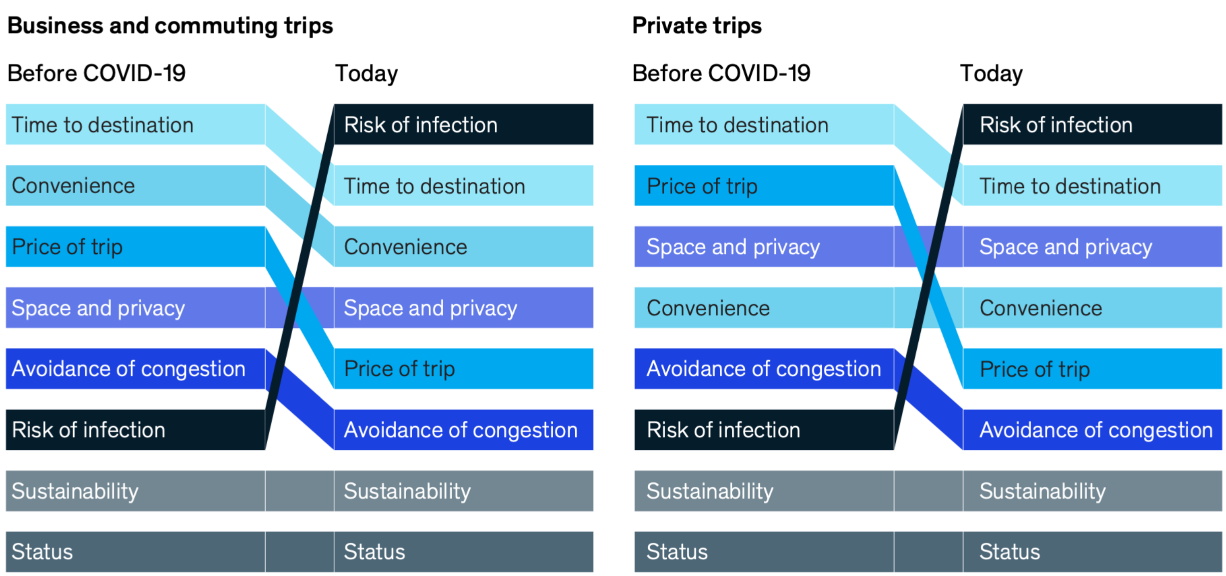


Figure 5.0.1: Key reasons to choose a mode of transport [90]

Within the transportation sector, now modes that are considered to be safe and hygienic are more preferred than others. This could mean an increase in private car ownership and a decrease in users for car sharing and public transport, as seen in the USA. In fact, the marketing survey curated for this thesis also yielded a similar result, with the majority of respondents opting for private vehicles for commuting as seen in Figure 5.0.2. Also reports of cities making more bike and scooter lanes are coming up, with more people shifting from public transportation mode to private transport [90].

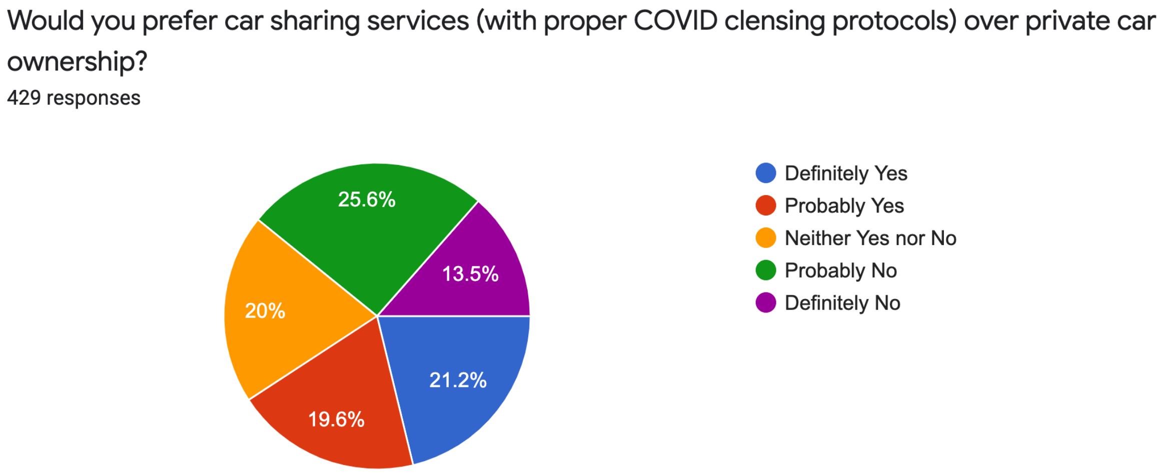


Figure 5.0.2: Survey results - car sharing services

With a wide spread shift in consumer preferences, some of the new changes are likely to persist long after the pandemic has subdued:

1. Micro-mobility solutions like bicycles, e-scooters, mopeds, quadricycles etc are likely to have more customers due to widespread awareness about health and safety.

2. Pace of change in technology will continue to increase in areas like autonomous driving, urban transportation and connectivity.

3. Regulations for curtailing CO_2 emissions are expected to increase as agencies and governments look to control climate change and pollution. With the lockdowns during the pandemic, people experienced fresh clean air in decades in almost all cities around the world, thus increasing awareness of the said issue.

4. Online channels for various businesses have emerged or become more streamlined and offer more efficient and easy support and services for both users and service providers. Automotive purchases have increasingly shifted to an online platform during the pandemic to offer a new and completely different experience to customers.

6. Future of urban mobility

Figure 6.0.1: A visualisation of urban mobility in the future [91]

In cities with increasing traffic congestion, the only faster way to get from one point to another in the future would be by air. Short air travel or air taxis are predicted to be the future of automobile companies beyond electric cars. More automobile companies like GM (General Motors) and Audi have been creating prototypes of eVTOL (Electric Vertical Take-off and Landing) aircrafts for use in urban environments for transporting people and goods [99][100]. Figure 6.0.2 shows the digital prototype of an eVTOL air taxi shown by Cadillac at CES 2021 is a glimpse into the future of cars. And e-commerce companies like Amazon are looking forward to automated drone technology to deliver their products [101].

These low flying air taxis or eVTOL aircrafts are suggested to be either remotely controlled by a trained pilot or are to be fully automated to fly and the user could control a few non-critical choices like where to land etc. With 5G communication technology onboard, it would be possible to enable remote maneuvers for the aircraft. However with aircrafts, the front cross-section of the craft is as important as the weight of the craft in order to increase maneuverability and also reduce drag. This would make the 1+1 seating arrangement similar to the proposed quadricycle very important to research about and improve upon, to decrease the front cross-sectional area of such flying taxis discussed above.

Figure 6.0.2: GM’s Cadillac eVTOL air taxi [100]

Even though there is a huge interest surrounding flying taxis, experts suggest that noise pollution from the rotors of larger eVTOL aircrafts will probably restrict the use of these vehicles to extra-urban commutes from outer limits of the city. But smaller automated eVTOL aircrafts for carrying goods could qualify to be used within city limits due to lower noise levels from rotors.

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