SED FUND

VASUDHA
FOUNDATION
Green ways for a good earth!

ASSESSING DEEP ELECTRIFICATION AS A VECTOR TO ABATE EMISSIONS IN THE TRANSPORT SECTOR

Authors

Jaideep Saraswat, Nikhil Mall, Varun B.R.

Reviewers

Srinivas Krishnaswamy, Raman Mehta

Editorial

Swati Bansal

Design

Santosh Kumar Singh

About Vasudha Foundation

Vasudha Foundation is a non-profit organisation set up in 2010. We believe in the conservation of Vasudha, which in Sanskrit means the Earth, the giver of wealth, with the objective of promoting sustainable consumption of its bounties. Our mission is to promote environment-friendly, socially just and sustainable models of energy by focusing on renewable energy and energy-efficient technologies as well as sustainable lifestyle solutions. Through an innovative approach and data- driven analysis, creation of data repositories with cross-sectoral analysis, along with outreach to ensure resource conservation, we aim to help create a sustainable and inclusive future for India and Mother Earth.

About SED Fund

Stichting SED Fund is a philanthropic initiative to support the Sustainable Development Goals (SDGs) of clean air, access to energy, clean water, climate action and equity, by backing efforts of governments and civil society on clean energy transition, according to principles of sustainability, diversity and equity. We amplify impact by consolidating philanthropic resources, strengthening country level institutions and civil society groups and supporting initiatives that will have the most impact in support of these goals.

Disclaimer

This report is based on the best available information in the public domain. Every attempt has been made to ensure the correctness of data. However, Vasudha Foundation does not guarantee the accuracy of the data or accept responsibility for the consequences of using the same.

Copyright

CISRS House, 14 Jangpura B, Mathura Road, New Delhi - 110014
For more information, visit www.vasudha-foundation.org

CONTENTS

LIST OF TABLES

LIST OF FIGURES

INTRODUCTION

The transport sector in India is one of the fastest-growing sectors in our economy estimated to grow at a CAGR of 5.9 percent[1]. It is also the third-highest emission-intensive sector in the country. According to a prominent emission repository in 2018, the transport sector accounted for 12.38 percent of total emissions arising from fuel combustion in the country[2]. In light of India's updated Nationally Determined Contributions (NDCs) to reduce the emissions intensity of its GDP by 45 percent by 2030 (from 2005 levels) and achieve a 50 percent share of cumulative electric power installed capacity from non-fossil fuel-based energy resources by 2030[3], decarbonisation of the transport sector is critical.

Broadly, the transport sector in India can be classified into the following categories – Road, Railway, Maritime, and Aviation. Road transport is responsible for over 90 percent of the total energy consumption, thus prioritising it as a sub-sector for urgent decarbonisation. Also, the emissions intensity from road transport is concomitantly the highest as the majority of the sector continues to be powered by fossil-fuel-based sources.

As India moves steadfastly towards incorporating a higher share of Renewable Energy (RE) in its power mix, electrification of the transport sector is viewed as a low-hanging fruit towards achieving sectoral decarbonisation. Further, an assessment that was conducted to determine the priority sectors for deep electrification identified the transport sector as receiving a high priority[4]. Deep electrification of the transport sector is to be viewed in two tranches – Direct and Indirect Electrification. Road transport has the potential to achieve 100 percent direct electrification, whereas aviation and maritime sectors can be decarbonised by adopting sustainable fuels produced through clean energy sources. Owing to this indirect form of electrification, they are aptly labelled as hard-to-abate sectors vis-à-vis decarbonisation. This report captures key insights into the process of electrifying the transport sector in India.

---

[1] https://ficci.in/sector.asp?sectorid=22

[2] https://www.ghgplatform-india.org/energy-sector/

[3] https://pib.gov.in/PressReleaseIframePage.aspx?PRID=1847812

[4] Vasudha Foundation Analysis

1 CURRENT SCENARIO OF TRANSPORTATION IN INDIA

In India, the road transport sector accounts for more than 87 percent of passenger traffic and about 60 percent of freight traffic movement in the country[5]. A target to electrify 30 percent of road transport has been set by 2030[6]. The hard-to-abate sectors such as maritime and aviation does not have dedicated electrification targets. On the contrary, the Indian Railways stands as a leading sub-sector vis-à-vis electrification. About 83 percent of the Broad-Gauge Network[7] has been electrified and a target to achieve 100 percent electrification by the end of FY 2023-24[8] has been notified. In this section, an overview of fossil-fuel-derived emissions share for each of the broad sub-sectors is provided. This highlights the scope of emission abatement that can be realised through a deep electrification strategy.

ROAD

As previously mentioned, road transport has the highest quantum of total energy consumption within the larger transport sector. Primarily the pollutants[9] arising from transport include CO_2, NOx, CO, and NMVOCs (which act as a precursor to Particulate Matter[10]). A glance into the sub-categories of road transport highlights the most polluting vehicle segments. As observed in Figure 1, freight vehicles (Heavy Duty Vehicles and Light Duty Vehicles) and personal transport vehicles (Two-wheelers and Cars) contribute to about 74 percent share of the total CO_2 emissions in road transport.

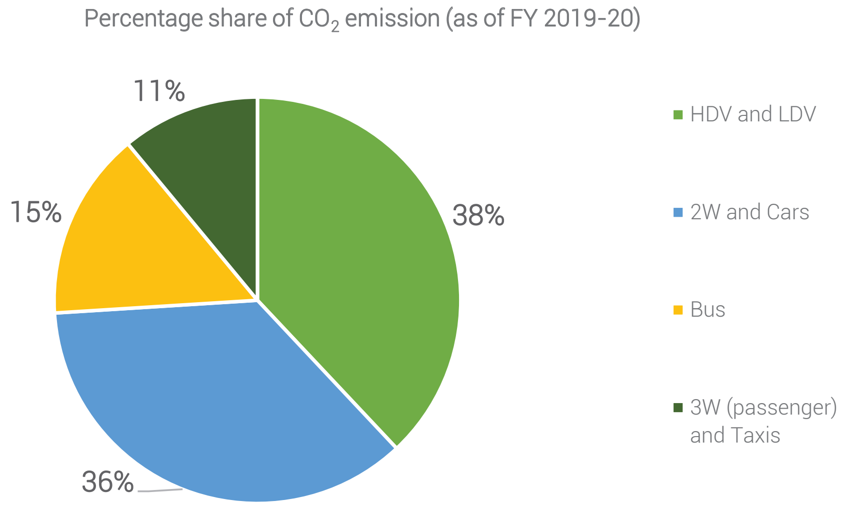


Figure 1: Vehicle segment-wise percentage share of CO_2 emissions in road transport[11]

---

[5] https://morth.nic.in/road-transport

[6] https://e-amrit.niti.gov.in/national-level-policy

[7] chrome-extension://efaidnbmnnnibpcajpcglclefindmkaj/https://pqals.nic.in/annex/1710/AU2468.pdf

[8] chrome-extension://efaidnbmnnnibpcajpcglclefindmkaj/https://indianrailways.gov.in/railwayboard/uploads/directorate/secretary_branches/IR_Reforms/Mission%20100%25%20Railway%20Electrification%20-%20Moving%20towards%20Net%20Zero%20Carbon%20Emission.pdf

[9] chrome-extension://efaidnbmnnnibpcajpcglclefindmkaj/https://www.ipcc-nggip.iges.or.jp/public/gp/bgp/2_3_Road_Transport.pdf

[10] https://www.canada.ca/en/environment-climate-change/services/air-pollution/pollutants/common-contaminants/volatile-organic-compounds.html

[11] https://www.researchgate.net/publication/350596826_Emissions_inventory_for_road_transport_in_India_in_2020_Framework_and_post_facto_policy_impact_assessment

Based on the fuel type used in road transport, Figure 2 illustrates the highest polluting vehicles for CO, NOx, and PM emissions. In the year of consideration (FY 2019-20), petrol vehicles constituted more than 87 percent[12] of the road vehicles in India, however, we observe that the emissions quantum does not correspond. Diesel vehicles with a smaller share in on-road presence contribute a disproportionately high share in emissions. We observe that diesel has emission units (>1) across the pollutants indicative of a larger emission quantum share. In the case of PM emissions, CNG has particulate matter of size that is smaller than the regulated emission limit of 23 nm. Owing to its negligible magnitude within the regulated limit, it has been clubbed with diesel.[13]

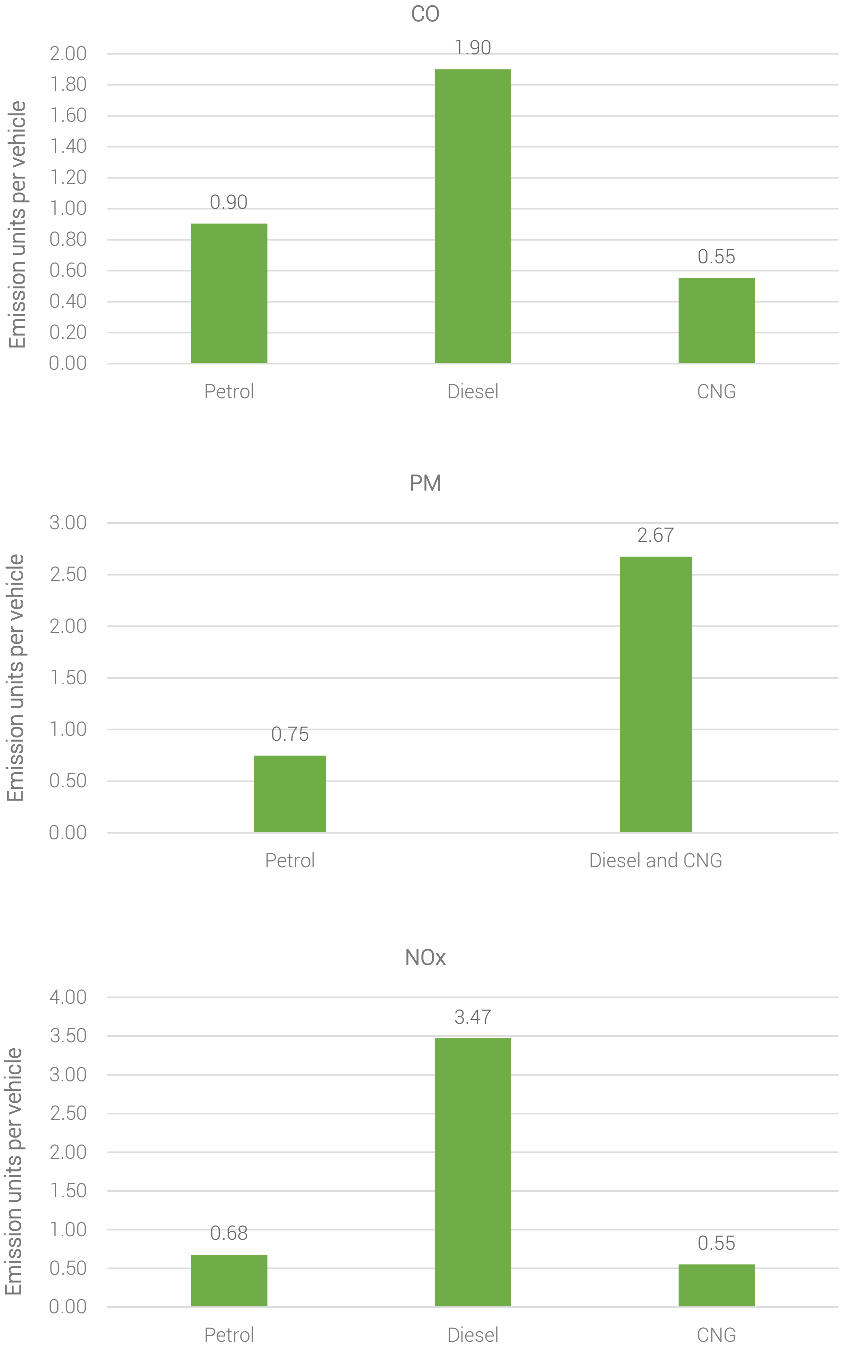


Figure 2: Emission units per vehicle corresponding to CO, PM, and NOx emissions by fuel-type of road transport vehicles[14]

---

[12] Vasudha Analysis from source link- https://vahan.parivahan.gov.in/vahan4dashboard/

[13] https://www.tandfonline.com/doi/full/10.1080/02786826.2020.1830942

[14] https://www.researchgate.net/publication/350596826_Emissions_inventory_for_road_transport_in_India_in_2020_Framework_and_post_facto_policy_impact_assessment

MARITIME

In 2018, the Directorate General of Shipping (DGS) issued a circular that categorised Indian ships into three groups as observed in Table 1. The International Maritime Organisation's Data Collection System mandated the creation of a repository of consumption data for each type of fuel oil used for all ships exceeding 5000 Gross Tonnage (GT) in volume. In compliance, the DGS reflected India's commitments to reduce GHG emissions from ships and prescribed the mandate for all Indian vessels registered under the Merchant Shipping Act.

Table 1: Ship categories notified by the Directorate General of Shipping[15]

Category	Description
1	Ships with Gross Tonnage ≥ 5000, certified for international voyages
2	Ships with Gross Tonnage ≥ 5000 in accordance with Indian Coastal Vessel Notification
3	Ships with Gross Tonnage ≤ 5000

The overall consumption of fuels by Indian vessels resulted in about 5.1 million tonnes of CO_2 emissions in 2019[14]. In 2020, the impact of the COVID pandemic resulted in a decline in emissions to about 4.62 million tonnes of CO_2 emissions[14]. Figure 3 represents the share of emissions corresponding to the type of fuel used across all the categories of ships in 2020.

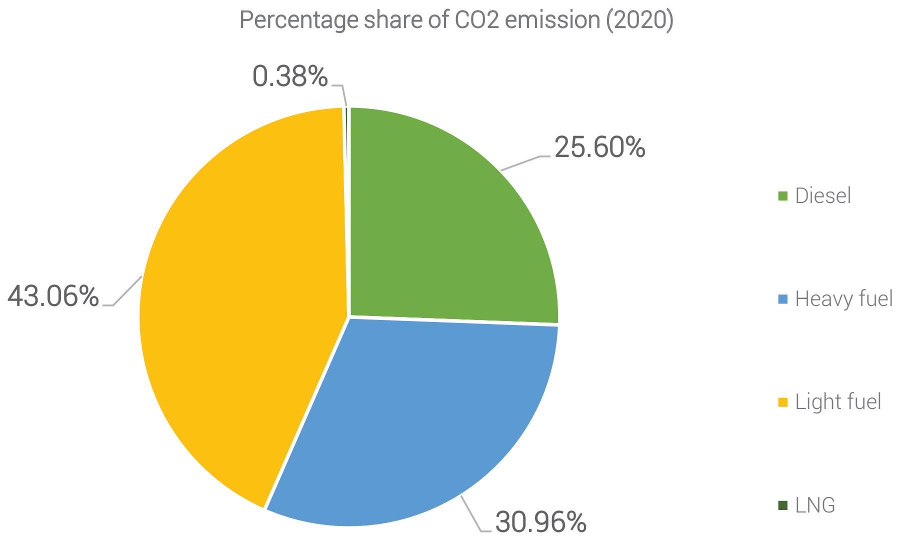


Figure 3: Fuel-wise emission share of all Indian Vessels in 2020[14]

In 2020, a total of 876 Indian vessels were operational[14]. About 72 percent of these vessels belonged to Category-3 type of ship[16]. However, the majority of the emissions (~80.3 percent) were attributed to Category-1 vessels primarily owing to their large size and long distances travelled. Figure 4 illustrates the various ship types present in each category and their corresponding share in emissions for the year 2020.

---

[15] chrome-extension://efaidnbmnnnibpcajpcglclefindmkaj/https://www.dgshipping.gov.in/WriteReadData/CMS/Documents/202207281020069898266202207151041353645818AnnualFuelConsumptionReport2019-2020.pdf

[16] Vasudha Analysis from Annual Fuel Consumption Report for 2019 and 2020, Ministry of Ports, Shipping and Waterways.

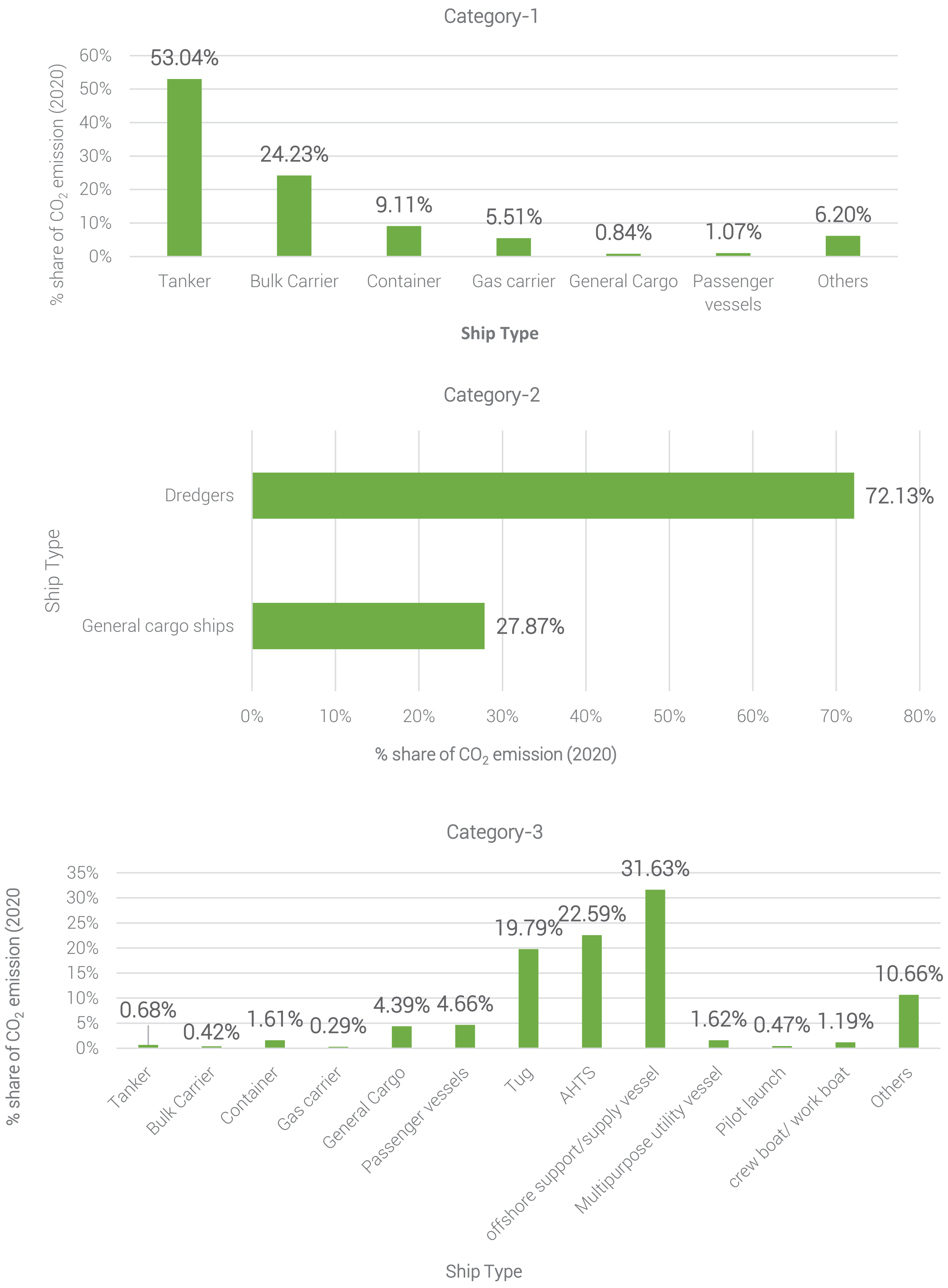


Figure 4: Ship-type percentage share of emissions corresponding to Indian vessel categories[14]

AVIATION

Indian aviation is powered by fossil-fuel derived aviation turbine fuel. As per the last available statistics by the Directorate General of Civil Aviation (DGCA), aviation turbine fuel consumption stood at 7.6 million tonnes, in FY 2017-18[17]. While electric and hydrogen-powered solutions continue to be probed globally, the feasibility of switching from existing aviation fuels remains unlikely. In India's nascent decarbonisation efforts concerning aviation – Sustainable Aviation Fuels (SAF) synthesised from renewable feedstocks stand as viable alternatives to fossil fuels.

In 2018, *SpiceJet* piloted India's first domestic SAF test flight with a 25 percent blend[16]. Further, SAF was also successfully tested on the Indian Air Force's AN-32 fleet. Currently, the cost of SAF is about 200 to 500 percent more expensive than conventional aviation fuels[16], thus limiting its widespread use. However, SAF has the potential to be 100 percent less carbon-intensive over its life-cycle[16]. Figure 5 illustrates the emission quantum from the aviation sector. The reduction in emissions in 2020 can be attributed to the COVID pandemic, however with growing fuel requirements, the emission quantum is expected to increase. With widespread adoption of SAF, there is a potential to significantly reduce emissions from this sector.

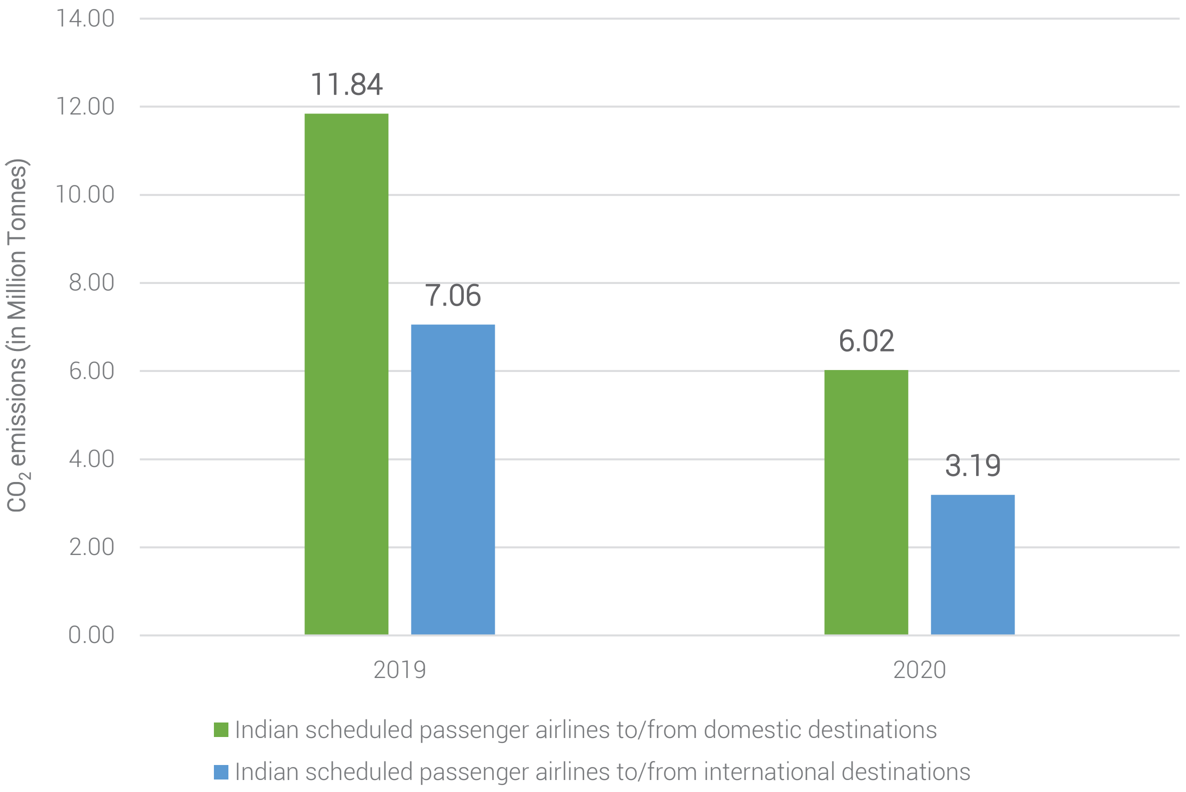


Figure 5: CO_2 emissions from the Indian Aviation sector[18]

---

[17] chrome-extension://efaidnbmnnnibpcajpcglclefindmkaj/http://164.100.60.133/pub/HANDBOOK%202017-18/HANDBOOK%202017-18.pdf

[18] https://www.pib.gov.in/PressReleasePage.aspx?PRID=1844621

2 KEY BARRIERS TO EFFECTIVE DECARBONISATION

The transport sector is crucial for every country's socioeconomic growth, and its significance cannot be overstated. Over 80 percent of passenger travel and more than 50 percent of freight traffic in India is carried by road[19]. With its participation in this goal-achieving process, transportation sector's contribution to achieving the SDGs becomes more relevant. There are various options available through which sustainable transportation can be achieved in the country.

The A-S-I (Avoid-Shift-Improve)[20] approach can be applied to promote the safe and sustainable development of road transport systems. The three pillars involve identifying and avoiding potential harms and negative impacts of transport while reducing their risk, shifting to more sustainable and efficient forms of transportation while maintaining mobility, and improving the performance and safety of road transport systems through the use of advanced technologies. Strategies to achieve these pillars may include improving road infrastructure, encouraging the use of alternative modes of transport, shifting freight movement to railways, and implementing intelligent transportation systems.

BARRIERS FOR ROAD SEGMENT

The barriers can be divided into four main heads:

- Technological barriers
- Consumer behavioural barriers
- Infrastructural barriers
- Government barriers

TECHNOLOGICAL BARRIERS

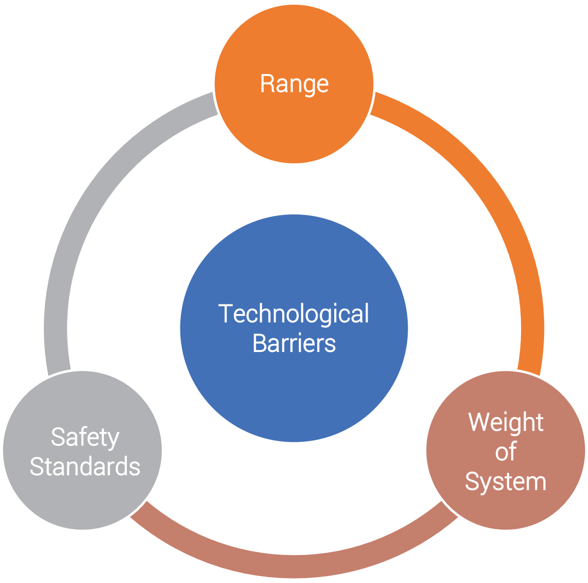


Figure 6: Technological barriers to the adoption of EV

---

[19] https://www.thebritishacademy.ac.uk/publications/all-change-equitably-decarbonising-indias-transportation-sector/

[20] https://www.transformative-mobility.org/wp-content/uploads/2023/03/ASI_TUMI_SUTP_iNUA_No-9_April-2019-Mykme0.pdf

The major obstacles to EV adoption include range limitations, safety concerns, packaging, component standards, and source of energy production. The technological barriers are broadly grouped as shown in Figure 6. EV range is impacted by battery capacity, weight, and aerodynamic drag, as well as a lack of charging infrastructure. Higher weight increases energy storage costs and deters consumer demand. Battery safety risks include thermal runaway, overheating, and fire. Battery disposal and the subsequent environmental damage also poses a significant concern, as current battery recycling technology is insufficient to support claims of a cleaner future.

INFRASTRUCTURE GAPS

EV Enroute Charging

Inhouse Charging

Nascent Battery
Swapping Ecosystem

Grid Stability Concerns

Figure 7: Areas of infrastructure barriers to EV adoption

Figure 7 lists the key areas of infrastructure barriers to mainstreaming EV adoption. The lack of sufficient on-road charging infrastructure is the main cause of range anxiety for potential EV buyers. Addressing this issue requires considering charging station specifications and safety regulations. EV charging also has indirect impacts on electricity transmission and storage, with EV grid integration affecting grid loading and voltage instability. Nonlinear loading characteristics of EV charging can decrease power reserve margins and cause power quality issues. Long-term hot spot temperatures can also decrease the lifespan of distribution transformers.

CONSUMER BEHAVIOUR

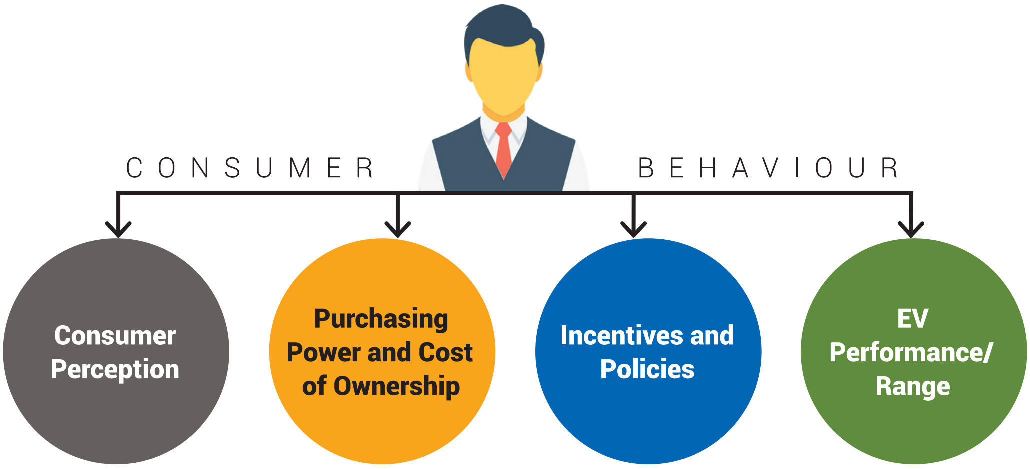


Figure 8: Consumer behaviour-related obstacles

The environmental benefits of EVs are not well understood, and customers prioritise performance over eco-friendliness. The various areas of ambiguity are as shown in Figure 8. Limited battery life options and the small number of EV manufacturers discourage potential buyers. Government regulations and incentives, such as financial advantages, can have a significant impact on EV purchases.

GOVERNMENT BARRIERS

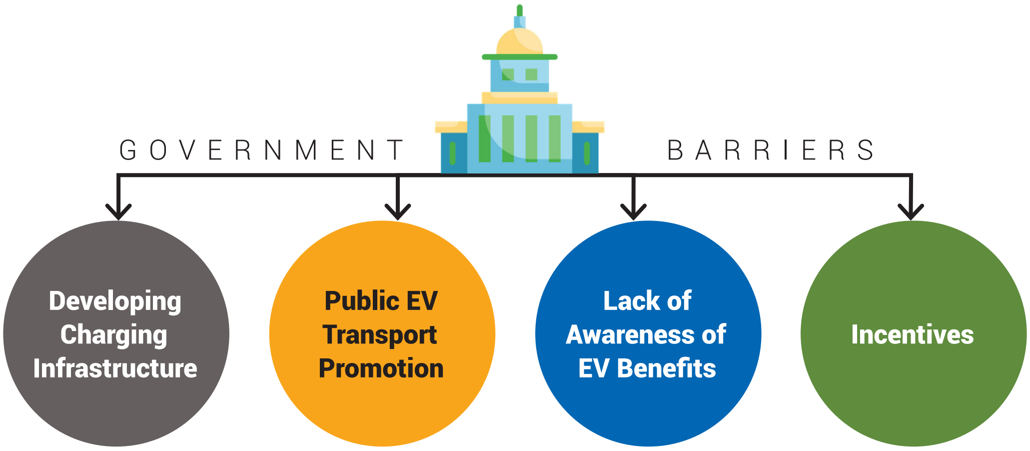


Figure 9: Government facets warranting improvement

Government support is crucial in promoting the EV market, including the development of public charging infrastructure and raising awareness about the environmental benefits of EVs as shown in Figure 9. Emphasising the electrification of public transport can also encourage EV adoption. The ASI (Avoid-Shift-Improve) approach, if adopted, can help overcome barriers to decarbonising road transport by identifying potential harms, shifting to more sustainable transport options, and improving performance through advanced technologies.

BARRIERS FOR THE MARITIME SEGMENT

Decarbonising the maritime sector is an essential step in achieving global climate goals, but there are several barriers that make this process challenging. Some of the key barriers include:

- **High costs**: Requires significant investment in new technologies, such as alternative fuels, new engines, and energy-efficient designs. These investments can be expensive, and the costs may be passed on to consumers, which could make shipping more expensive.
- **Limited availability of alternative fuels**: While there are many promising alternative fuels, such as biofuels, hydrogen, and ammonia, these fuels are not yet widely available. Developing the infrastructure necessary to produce, store, and transport these fuels is a significant challenge that requires coordination between governments, industry, and other stakeholders.
- **Regulatory barriers**: The regulatory framework for the maritime sector can be complex and may not be designed to incentivise decarbonisation. For example, there may be limited financial incentives for companies to invest in new technologies, and regulations may not require ships to meet certain emissions standards.
- **Technical challenges**: Requires developing and implementing new technologies, such as carbon capture and storage, which can be technically challenging. Additionally, retrofitting existing ships to meet new emissions standards can be difficult and expensive.
- **Global coordination**: Shipping is an international industry, and decarbonising the sector requires global coordination and cooperation. This can be challenging because different countries may have different priorities and interests, and there may be limited agreement on how to address climate change.

BARRIERS FOR AVIATION SEGMENT

India's aviation market is one of the world's fastest expanding markets. Its domestic traffic accounts for 69 percent of South Asia's overall airline traffic[21]. Over the past ten years, this industry has had average annual growth of 16 percent, primarily due to the rise in purchasing power of consumers and low-cost flying[22].

While India's aviation industry has been growing rapidly, it remains a major source of greenhouse gas emissions, emitting around 84.32 million tonnes of carbon dioxide between 2016-20[23]. It is responsible for approximately one percent of the country's total CO_2 emissions[24 & 25]. To decarbonise the sector, there are several barriers that need to be addressed. These include the sustainable production of aviation fuel, the electrification of aircraft, and the cost of sustainable aviation fuel. Concerning electrification of aircraft, the high weight of batteries acts as a barrier. Further, the higher cost of sustainable aviation fuel than fossil jet fuel is another barrier to the segment. Though India has the raw materials to produce sustainable aviation fuel, the manufacturing capacity needs to increase and mass deployment can bring the cost down.

One small way forward which can be adopted by all airlines is the electrification of its ground fleet of buses and other machinery. While non-flying related pollution is minimal as compared to the one caused by airplanes, this low-hanging fruit should not be avoided by aviation companies.

---

[21] https://prsindia.org/theprsblog/state-of-the-civil-aviation-sector-in-india?page=15&per-page=1

[22] https://cstep.in/drupal/sites/default/files/2022-09/GHGPI-PhaseIV-Briefing-Paper-on-Indias-Future-in-Sustainable-Aviation_CSTEP-Sep22.pdf

[23] https://www.pib.gov.in/PressReleasePage.aspx?PRID=1844621

[24] https://www.icf.com/insights/transportation/airports-contribute-india-sustainability-goals

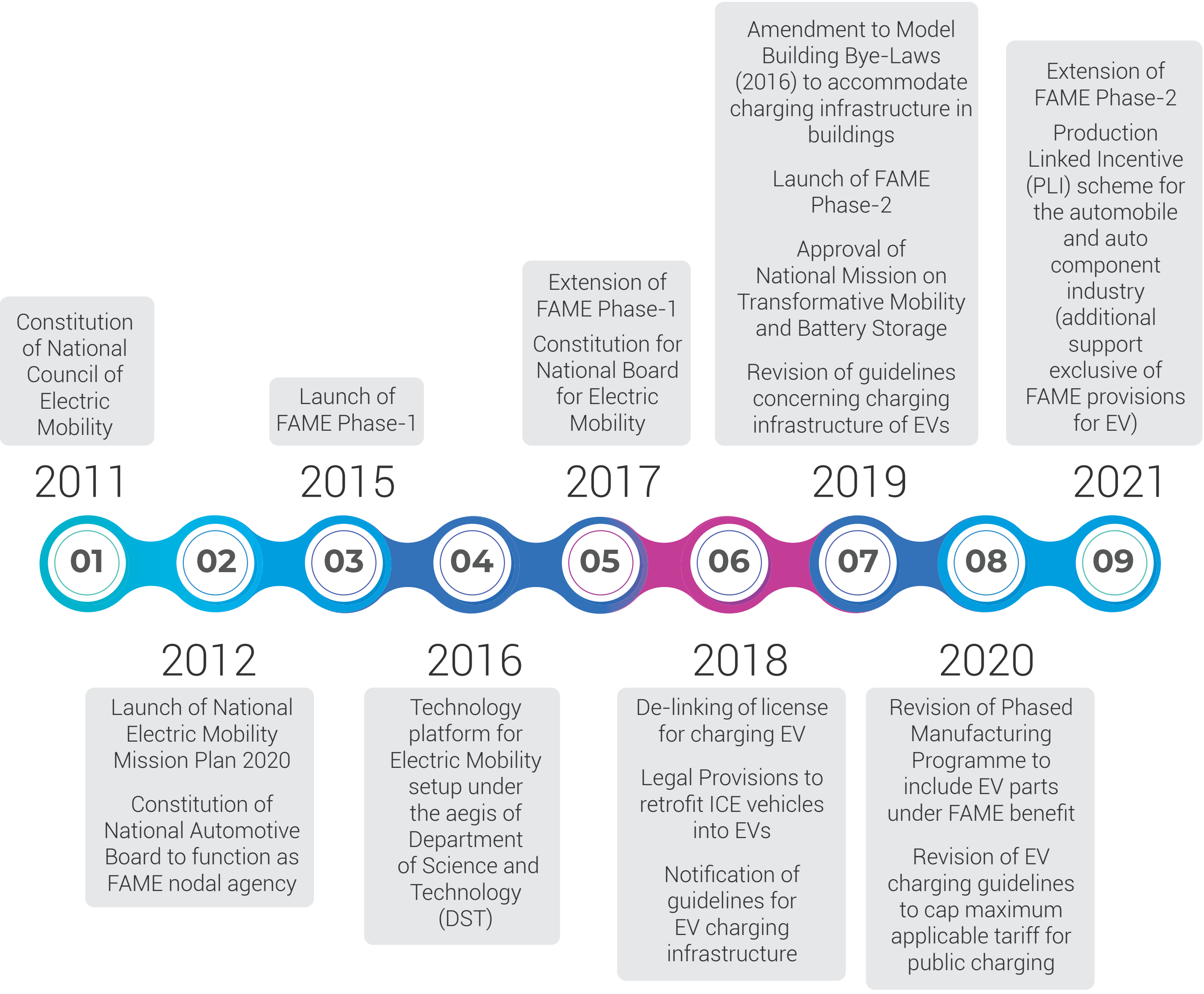
[25] https://www.ceew.in/publications/india-transport-energy-use-carbon-emissions-and-decarbonisation

3

POLICY LANDSCAPE FOR TRANSPORT ELECTRIFICATION IN INDIA

ROAD

India's policy push to facilitate EV adoption in the country was initiated with the formation of the National Council for Electric Mobility in 2011. Over a decade hence, multiple government initiatives have been launched to advance the e-mobility agendas. A timeline of the key initiatives is represented in Figure 10.



2011

Constitution of National Council of Electric Mobility

2012

Launch of National Electric Mobility Mission Plan 2020

Constitution of National Automotive Board to function as FAME nodal agency

2015

Launch of FAME Phase-1

2016

Technology platform for Electric Mobility setup under the aegis of Department of Science and Technology (DST)

2017

Extension of FAME Phase-1

Constitution for National Board for Electric Mobility

2018

De-linking of license for charging EV

Legal Provisions to retrofit ICE vehicles into EVs

Notification of guidelines for EV charging infrastructure

2019

Amendment to Model Building Bye-Laws (2016) to accommodate charging infrastructure in buildings

Launch of FAME Phase-2

Approval of National Mission on Transformative Mobility and Battery Storage

Revision of guidelines concerning charging infrastructure of EVs

2020

Revision of Phased Manufacturing Programme to include EV parts under FAME benefit

Revision of EV charging guidelines to cap maximum applicable tariff for public charging

2021

Extension of FAME Phase-2

Production Linked Incentive (PLI) scheme for the automobile and auto component industry (additional support exclusive of FAME provisions for EV)

Figure 10: Timeline of key e-mobility initiatives in India[26]

From the perspective of on-road presence, there are two key facets – procuring the EV, and charging the EV. In this regard, there are two focal ministries – Ministry of Heavy Industries (MHI) which has formulated the Faster Adoption and Manufacturing of (Hybrid &) Electric Vehicles (FAME) scheme, and the Ministry of Power (MoP) which legislates on charging infrastructure for electric vehicles in India. Additionally, as Figure 11 illustrates, there are other line ministries that support the electric mobility transition under the National Mission on Transformative Mobility and Battery Storage.

---

[26] https://e-amrit.niti.gov.in/national-level-policy

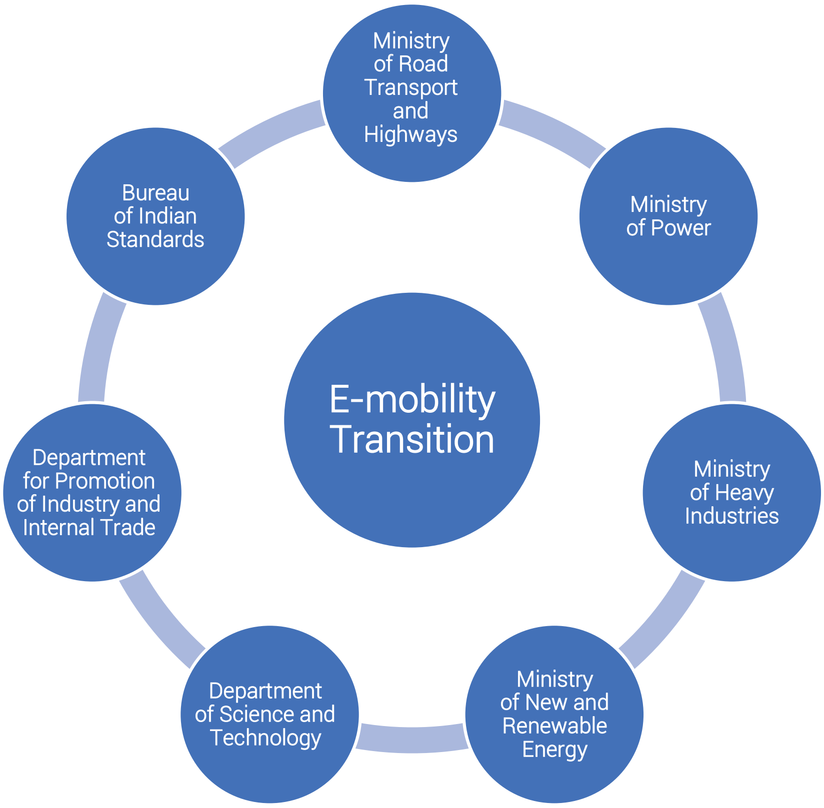


Figure 11: Government stakeholders supporting the E-mobility Transition

MARITIME

India is set to receive its first indigenously built hydrogen fuelled-electric vessel in 2023 under the aegis of the Cochin Shipyard Limited[27]. Further, a joint initiative by the Ministry of Ports, Shipping, and Waterways, and the Ministry of New and Renewable Energy, is proposed with the aim to power India's maritime sector solely by clean energy[28]. However, there is no active policy towards electrification (indirect) in the maritime sector, and the efforts are centred around monitoring GHG emissions with an intent to reduce the same.

At the global-level, the International Maritime Organization (IMO) constituted the Maritime Environment Protection Committee (MEPC) which was tasked with controlling and reducing emissions from ship-sources and other facets as included in the MARPOL[29] treaty. In 2018, the MEPC adopted a mandate to reduce GHG emissions via resolution *MEPC.278(70)*[30], which introduced the IMO Data Collection System (IMO DCS). According to IMO DCS, ships of 5,000 gross tonnage and above are required to collect consumption data for each type of fuel oil used, alongside specific data as detailed in the resolution that accounts for Dynamic Positioning (DP) vessels[31]. DCS follows a three-step approach where data collection is the preliminary step. In the subsequent steps, this data is to be analysed and decisions that aid in the reduction of GHG emissions are to be derived.

In alignment with India's commitments to reduce GHG emissions, the DGS notified requirements from Indian flag vessels to comply with IMO DCS. Moving a step beyond the international mandate, the DGS has

---

[27] https://pib.gov.in/PressReleaseIframePage.aspx?PRID=1821624

[28] https://www.livemint.com/industry/energy/centre-explores-plan-to-run-ships-fully-on-clean-energy-11641926148290.html

[29] The International Convention for the Prevention of Pollution from Ships

[30] chrome-extension://efaidnbmnnnibpcajpcglclefindmkaj/https://www.dgshipping.gov.in/WriteReadData/CMS/Documents/202207281020069898266202207151041353645818AnnualFuelConsumptionReport2019-2020.pdf

[31] DP vessels are ships that can maintain their position without using anchors by analysing wind and wave data to automatically course-correct. They are typically used in deep sea waters for research and drilling applications.

prescribed DCS requirements for all Indian Flag vessels registered under the Merchant Shipping Act. This policy push was implemented with a view to having a national maritime emissions inventory.

AVIATION

Similar to the Maritime sector, Indian aviation does not have an active policy push to incorporate indirect electrification to develop alternate hydrogen-fuelled electric planes or clean power-derived SAF. However, measures revolving around carbon mitigation[32] have been introduced by the Directorate General of Civil Aviation (DGCA), such as-

- Use of renewable energy to power airports and electrification of ground-handling vehicles.
- Increased maintenance protocols to improve aircraft operational efficiency
- Optimising airspace utilisation under Flexible Use of Airspace (FUA)

Further, the National Policy on Biofuels 2018 has expanded the scope of raw materials that can be procured for producing biofuels and permits the use of organic feedstocks that is not in conflict with food supply, and land-use concerns[33]. Given that SAF falls under the ambit of this policy, there is scope to develop a robust domestic supply to power the Aviation sector whilst meeting decarbonisation mandates.

---

[32] https://www.pib.gov.in/PressReleasePage.aspx?PRID=1844621

[33] chrome-extension://efaidnbmnnnibpcajpcglclefindmkaj/https://mopng.gov.in/files/article/articlefiles/Notification-15-06-2022-Amendments-in-NPB-2018.pdf

4 DEEP ELECTRIFICATION CAN ACT AS A SILVER BULLET

TECHNOLOGICAL PROPOSITIONS FOR DECARBONISING THE TRANSPORT SECTOR

GLOBAL SCENARIO

In 2021 global CO_2 emissions from the transport sector amounted to ~7.7 Gt CO_2, an increase of eight percent from 2020[34]. To illustrate the priority sectors for decarbonisation, Figure 12 shows the share of emissions attributed to various transport segments.

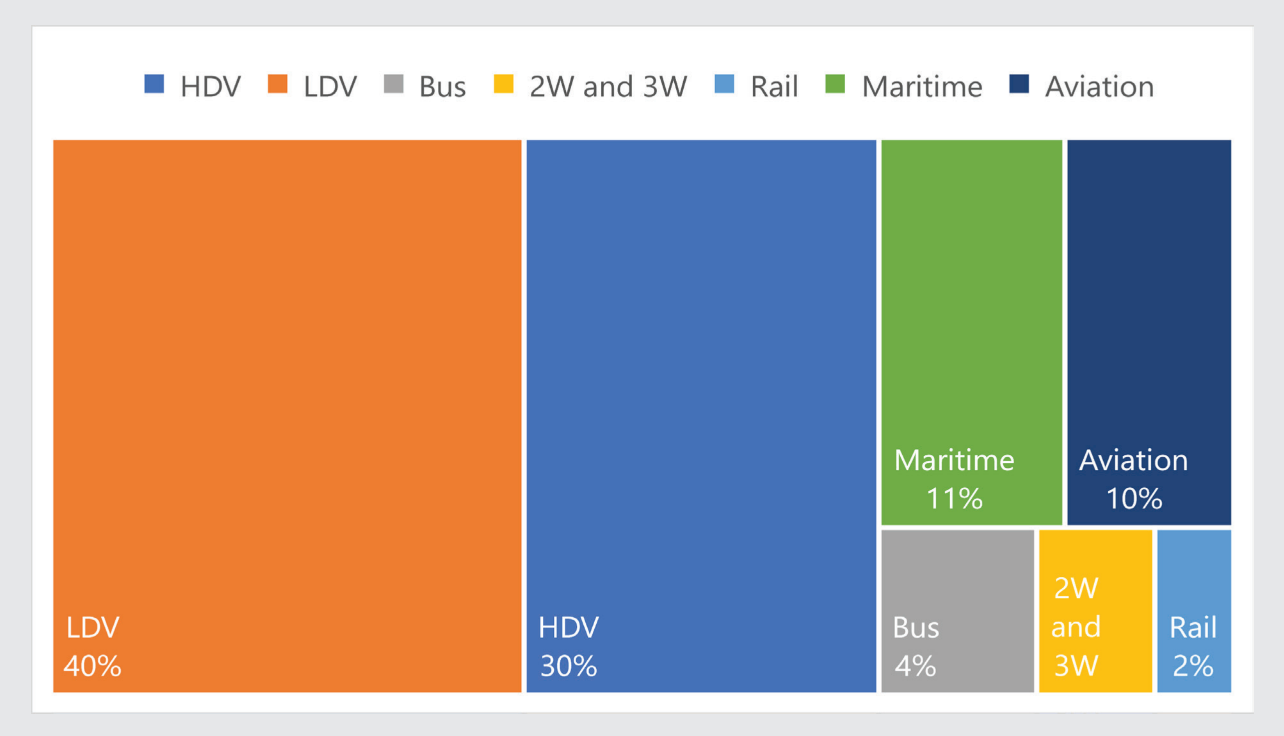


Figure 12: Share of well-to-wheel CO_2 emissions by transport segment (2020)[35]

Despite the expected increase in transportation requirements, meeting the Net Zero targets necessitates reducing transport sector emissions by approximately 20 percent to under 6 Gt by 2030[36]. Accomplishing this reduction requires prompt adoption of electric vehicles, operational and technological enhancements in energy efficiency, promoting and expanding the use of low-carbon fuels, especially in the aviation and maritime sub-sectors, and encouraging a shift towards less carbon-intensive travel options through appropriate policies. Within this, electrification has significant potential to mitigate emissions and decarbonise the sector. Table 2 provides an overview of the technological propositions for decarbonising the transport sector through electrification in the developed countries.

---

[34] IEA (2022). Transport. IEA. Paris. https://www.iea.org/reports/transport

[35] https://theicct.org/wp-content/uploads/2021/06/ICCT_Vision2050_sept2020.pdf

[36] IEA (2022). Transport. IEA. Paris. https://www.iea.org/reports/transport

Table 2: Transportation decarbonisation strategies through electrification by countries

Country	Roadways		Railways	Aviation	Maritime
	Buses/High Duty Vehicles	Light Duty Vehicles			
England[37]	1. 4000 zero emission buses (battery electric & hydrogen fuel cell); 2. Financial assistance at 22p/km	1. EVs 2. Recyclable electric batteries 3. High powered, open access charge points	1. Electrification 2. Hydrogen[38] 3. Battery	Hydrogen based (small no. of passengers)	Alternative fuel powered vessels: 1. Ammonia produced from hydrogen created using green electricity 2. Carbon capture and storage
United States[39]	1. Battery electric 2. Hydrogen fuel cell	1. Zero-emission EVs 2. Reduce battery costs to $80–100/kWh	1. Overhead catenary charging 2. Third-rail systems 3. Electric batteries 4. Hydrogen fuels	1. Sustainable aviation fuels- fully interchangeable, drop-in liquid hydrocarbon fuels 2. Battery electrification 3. Hydrogen fuel	1. Battery electrification options for smaller vessels 2. Cold Ironing[40] 3. R&D on fuel alternatives like ammonia, hydrogen, methanol etc
Germany[41]	1.Electrification of the bus drive system through battery and fuel cell solution (3,400 by 2025[42]) 2. For long-haul trucks: battery electric vehicles (BEVs), battery electric vehicles using an overhead catenary infrastructure (OC-BEVs)[43]	1. Hybrid vehicles 2. Greater use of zero-emissions vehicles	1. Provision of green electricity to factories, offices and stations 2. Building new infrastructure for battery powered trains 3. Supplying fuel cell trains with hydrogen 4. Using synthetic fuels on road and rail	1. Using biokerosene as an alternative fuel 2. Future pathway for engines (Expand R&D): Algae fuel ↓ Electricity-to-kerosene ↓ Hydrogen	1. Use of alternative energies 2. Shore-side electricity supply 3. Use of fuel cells is being tested as an efficiency measure and to cover the power required 'on board' 4. LNG as a fuel for inland vessels.

---

[37] Department for Transport. (2021).*Decarbonising Transport: A Better, Greener Britain*. https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/1009448/decarbonising-transport-a-better-greener-britain.pdf

[38] https://www.networkrail.co.uk/wp-content/uploads/2020/09/Traction-Decarbonisation-Network-Strategy-Interim-Programme-Business-Case.pdf

[39] Office of Energy Efficiency & Renewable Energy. (2022). *The U.S. National Blueprint for Transportation Decarbonization: A Joint Strategy to Transform Transportation.* https://www.energy.gov/sites/default/files/2023-01/the-us-national-blueprint-for-transportation-decarbonization.pdf

[40] Cold ironing is a practice of supplying electrical power to ships from the shore while they're docked. This way ships get to turn off their auxiliary diesel engines, reducing 95 % of air emissions.

[41] https://www.h2euro.org/wp-content/uploads/2013/09/German-Mobility-and-Fuels-Strategy.pdf

[42] https://www.sustainable-bus.com/news/zero-emission-germany-pwc-e-bus-radar/#:~:text=According%20to%20current%20plans%2C%20the,5%2C500%20additional%20electrically%20powered%20buses.

[43] Transport & Environment (2021). *How to decarbonise long-haul trucking in Germany. An analysis of available vehicle technologies and their*

Country	Roadways		Railways	Aviation	Maritime
	Buses/High Duty Vehicles	Light Duty Vehicles			
New Zealand[44]	Using LETF[45] to invest in: 1. Bespoke-built trucks ranging from 4–20t 2. Medium (4t) and heavy vehicles (29t) with battery swap technology 3. Hydrogen fuel cell trucks	1. Continue to incentivise the uptake of low and zero-emissions vehicles through the Clean Vehicle Discount[46] 2. Vehicle scrap-and-replace scheme (the Clean Car Upgrade[47]) and a social leasing scheme	1. Use of biofuels 2. Electrification 3. Hydrogen	Using sustainable aviation fuel (SAF).	1. Undertake research to advance development & uptake of alternative low & zero-carbon fuels for shipping such as green methanol 2. Use of low carbon technologies like wing-in-ground craft

KEY TAKEAWAYS

- Electrification of buses through batteries is one of the most affordable and accessible decarbonisation solutions for governments.
- Decarbonisation of LMVs/ personal cars by shifting to EVs is proving difficult due to its high cost. Studies have shown that simply switching to electric but not reducing the number of private cars is not a sustainable option[48].
- Railways has emerged as the most environment-friendly mode of long transport with the least amount of CO_2 emission per person per km. Governments are looking to invest in expanding the modal share of railways. Primary electrification options comprise of overhead catenary charging or batteries.
- Decarbonisation of aviation is technologically most challenging and will require multiple years before a commercial zero-emission option is viable.
- Maritime decarbonisation has focussed more on onshore electrification and mitigating on-board emissions as zero-emission engines are still a few years from becoming viable.

---

associated costs. https://www.transportenvironment.org/wp-content/uploads/2021/07/2021_04_TE_how_to_decarbonise_long_haul_trucking_in_Germany_final.pdf

[44] New Zealand Government. (2022). Decarbonising Transport Action Plan 2022–25. https://www.transport.govt.nz/assets/Uploads/MOT4716_Emissions-Reduction-Plan-Action-Plan-P04-V02.pdf

[45] Low Emission Transport Fund

[46] The scheme places a charge on high-emitting vehicles at the point of first registration in Aotearoa New Zealand to disincentive their purchase. Revenue from those charges is used to fund significant rebates on low zero-emissions vehicles to encourage their uptake

[47] Participants will be supported to scrap their high-emitting vehicles and replace them with low-emissions transport, such as low-emissions vehicles, bikes, e-bikes, public transport, low-emissions car-share and vehicle leasing. To encourage people to opt for low-emissions alternatives, the level of financial assistance received for these choices will be the same as that received for an EV. The scheme will be implemented on a trial basis from APRIL 2023.

[48] https://www.h2euro.org/wp-content/uploads/2013/09/German-Mobility-and-Fuels-Strategy.pdf

ROADWAYS

Within roadways, electrification of buses through batteries has emerged as one of the most affordable and accessible decarbonisation solutions for governments. Both England and Germany plan to phase out sales of new non-zero emission coaches within the next decade. For LDVs, electric vehicles (EVs) remain the primary strategy for decarbonisation. But the higher cost of buying an EV as compared to a traditional fuel-based vehicle has limited the growth of EVs even in developed countries. A lot of R&D is being driven towards recycling and minimising the cost of electric batteries.

RAILWAYS

Railways are considered one of the most environment friendly modes as it has the least carbon footprint of travel per kilometre[49]. Developed countries such as England and Germany with an existing dense network of railways are working towards expansion and complete electrification as part of their decarbonisation strategies. The United States, due to its large size, has identified overhead catenary charging as its ideal strategy for decarbonisation. Most of the R&D is being directed towards hydrogen and biofuels but they remain some years away from becoming viable.

AVIATION

The aviation sector falls among the hard-to-abate sectors as transition to cleaner fuels is currently unviable. Hydrogen-run aircraft remains the long-term goal for most developed countries with England planning to launch a small-scale one soon. A large, commercially viable aircraft run on hydrogen is still 10-15 years away from becoming viable. Instead, sustainable aviation fuels (SAFs) have emerged as the most practical solution for decarbonisation in the near future. Germany has identified using biokerosene as an alternative fuel.

MARITIME

Similar to aviation, alternative fuel-powered vessels at a large scale still remain commercially unviable for developed countries. Battery electrification and hydrogen-powered small-scale vessels are being tested. New Zealand is developing green methanol as one of the alternative fuels for maritime transport. Germany is testing LNG fuel among other options. The sector has focused more on on-shore and on-board electrification to reduce its carbon footprint through techniques such as cold ironing.

INDIA'S PERSPECTIVE

India's thought leadership on decarbonisation pathways for Road Transport and Railways largely lies under the ambit of direct electrification. Indian Railways are on the verge of attaining 100 percent electrification. Meanwhile hydrogen fuel cell vehicles for road transport are yet to attain commercialisation. The Maritime and Aviation sectors in India foresee indirect electrification pathways via synthetic fuels produced from renewable energy. A brief on India-specific technology options for the transport sector is given below-

Road Transport[50]: Electric vehicles and hydrogen fuel-cell vehicles lead India's clean fuel alternatives for road transport. The two-wheeler, three-wheeler, four-wheeler, and bus segments have commercialised battery-operated alternatives. Table 3 illustrates the key characteristics of commercially available Lithium-ion battery options at the cell level.

---

[49] https://ourworldindata.org/travel-carbon-footprint

[50] chrome-extension://efaidnbmnnnibpcajpcglclefindmkaj/https://static.psa.gov.in/psa-prod/publication/ev.pdf

Table 3: Characteristics of commercially available Lithium-ion technologies[51]

Battery	Lithium Manganese Oxide (LMO)	Nickel Manganese Cobalt Oxide (NMC622)	Nickel Cobalt Aluminium Oxide (NCA)	Lithium Iron Phosphate (LFP)	Lithium Titanium Oxide (LTO) – LMO
Description	High thermal stability limit coupled with high c-rates with minimal cell internal resistance. Low-cost is an added attraction.	Variation based on concentration of Nickel, Manganese, and Cobalt yields varied performance capabilities. NMC622 has higher performance characteristics in comparison to NMC111 or NMC811	High-energy density property thus making it preferred for long-range applications. However, not suited for high-power applications and functions optimally at lower c-rates.	High thermal stability limits, but low energy density levels. Suitable for heavy-duty transport, where larger batteries can be accommodated.	LTO is the anode and LMO is the cathode. The anode-induced properties yield high cycle life and high c-rate capabilities within acceptable safety limit. Suitable for fast-charging applications.
C-rate capability range	C/4 – 3C	C/4 – 2C	C/4 – 1C	C/4 – 2C	C/4 – 10C
Average Energy Density (Wh/kg)	149	250	255	136.5	79.5
Thermal Stability Limit (in °C)	250	210	150	400	250
Cycle Life (Charge -Discharge)	800 – 1000	3800 – 4000	1000 – 1500	3800 – 4000	8000 – 10000

Further, policymakers are also exploring Zero-Emission-Trucks (ZETs) including battery-electric and fuel-cell electric trucks[52]. Despite the low operating costs of battery electric trucks, the battery capacity limitations result in a low range compared with truck usage. Heavier batteries result in lower payload-carrying capabilities thus hampering its economic efficiency. Further, fuel-cell electric trucks are still a nascent technology and currently have high operating costs. However, technological advancements are expected to commercialise these low-carbon options.

Railways: India's broad gauge-network is rapidly undergoing electrification and will achieve 100 percent coverage by the end of FY 2023-24[8]. Alternately, hydrogen trains have been envisaged under the 'Hydrogen for Heritage' initiative by the Indian Railways[53]. Further, a pilot project that seeks to retrofit hydrogen fuel cell on existing Diesel Electric Multiple Units (DEMU) is also underway[28], thus indicating exploration of indirect electrification options as well for the sector.

---

[51] chrome-extension://efaidnbmnnnibpcajpcglclefindmkaj/https://www.wri-india.org/sites/default/files/State%20of%20Research%20%26%20Development%20in%20Electric%20Vehicle%20Battery%20Technology.pdf

[52] chrome-extension://efaidnbmnnnibpcajpcglclefindmkaj/https://www.niti.gov.in/sites/default/files/2022-09/ZETReport09092022.pdf

[53] https://pib.gov.in/PressReleasePage.aspx?PRID=1896102

Maritime Transport[54]: Policymakers concerned with the maritime sector consider hydrogen and hydrogen-derived fuels such as methanol and ammonia to be scalable solutions and to substitute marine bunker fuels. Transitional fuels such as Liquefied Natural Gas (LNG) have found recent significance owing to their partial GHG emission reduction capability. A high level of technology readiness makes methanol a promising fuel. However, supporting-infrastructure and regulatory standards are necessary to complement the scaling of Methanol. Other RE-derived synthetic fuels will require technological advancements to improve their viability. Further on the direct electrification front, electric boats, and ferries have high technology readiness which can be quickly scaled by suitable financial interventions.

Aviation: Alternate propulsion systems such as battery-powered and hydrogen-powered aircraft have high decarbonisation potential of achieving close to 100 percent emission reduction[55]. However, the technology readiness is low for these options. Alternately, sustainable aviation fuels have high decarbonisation potential and relatively higher technology readiness. They can be synthesised from municipal and agricultural waste, and the recent amendments to the national bio-fuel policy open additional avenues for raw material procurement. India has piloted SAF-blend-powered aircraft, and further technological maturity will propel SAF derived from renewable energy as a significant vector to indirectly electrify Indian aviation[16].

EXPECTED FUTURE SCENARIOS OF TRANSPORTATION IN INDIA

ROAD

As established in the previous sections, road transport presents a diverse set of vehicle segments and is a focal point from a decarbonisation perspective. In this section, we capture a scenario-based impact of the expected growth in road transport over the facets of emission intensity, and energy consumption. There are two scenarios in consideration- Business-As-Usual (BAU) and a high-ambition scenario as defined by the International Council on Clean Transportation (ICCT). The BAU scenario reflects an extension of current policy efforts without accommodating any new policy interventions for the transport sector. Under the high-ambition scenario, new policy interventions are accounted for which could result in exceeding the current policy targets. Ambitious decarbonisation policies are considered a reality under this scenario through the effective adoption of global best practices.

Emission Intensity: Under the BAU scenario, the total CO_2 emissions considered as part of the projections comprised of tank-to-wheel emissions, and grid electricity emissions attributed to electric vehicles. In the high-ambition scenario, high levels of electrification are achieved, supported by continued energy efficiency measures till 2050. As illustrated in Figure 13, the scenario-based variations in emission intensity across vehicle segments can be observed in the decades leading to 2050. In the BAU scenario, a rise in emissions is observed across all vehicle segments. The passenger cars segment is almost tripling in their emissions quantum by 2050. The buses and trucks segments have the highest projected increase at 312.45 percent and 299.55 percent respectively, by 2050, compared with 2020 levels.

In the high-ambition scenario, the two-wheeler and three-wheeler segments portray significant emission reduction. By 2050, an 82.16 percent emission reduction in two-wheelers, and a corresponding 79 percent reduction in three-wheelers is expected, compared with 2020 levels. Despite active decarbonisation efforts, the buses, and trucks segment, continue to have increased emissions. Compared with 2020 levels, the emission intensity from buses, and trucks is expected to see an increase of about 23 percent in both segments by 2050.

---

[54] chrome-extension://efaidnbmnnnibpcajpcglclefindmkaj/https://www.dgshipping.gov.in/WriteReadData/userfiles/file/Green%20Shipping%20Conclave%20Outcomes%20Report_06012023_Final.pdf

[55] chrome-extension://efaidnbmnnnibpcajpcglclefindmkaj/https://www.ghgplatform-india.org/wp-content/uploads/2022/09/GHGPI-PhaseIV-Briefing-Paper-on-Indias-Future-in-Sustainable-Aviation_CSTEP-Sep22.pdf

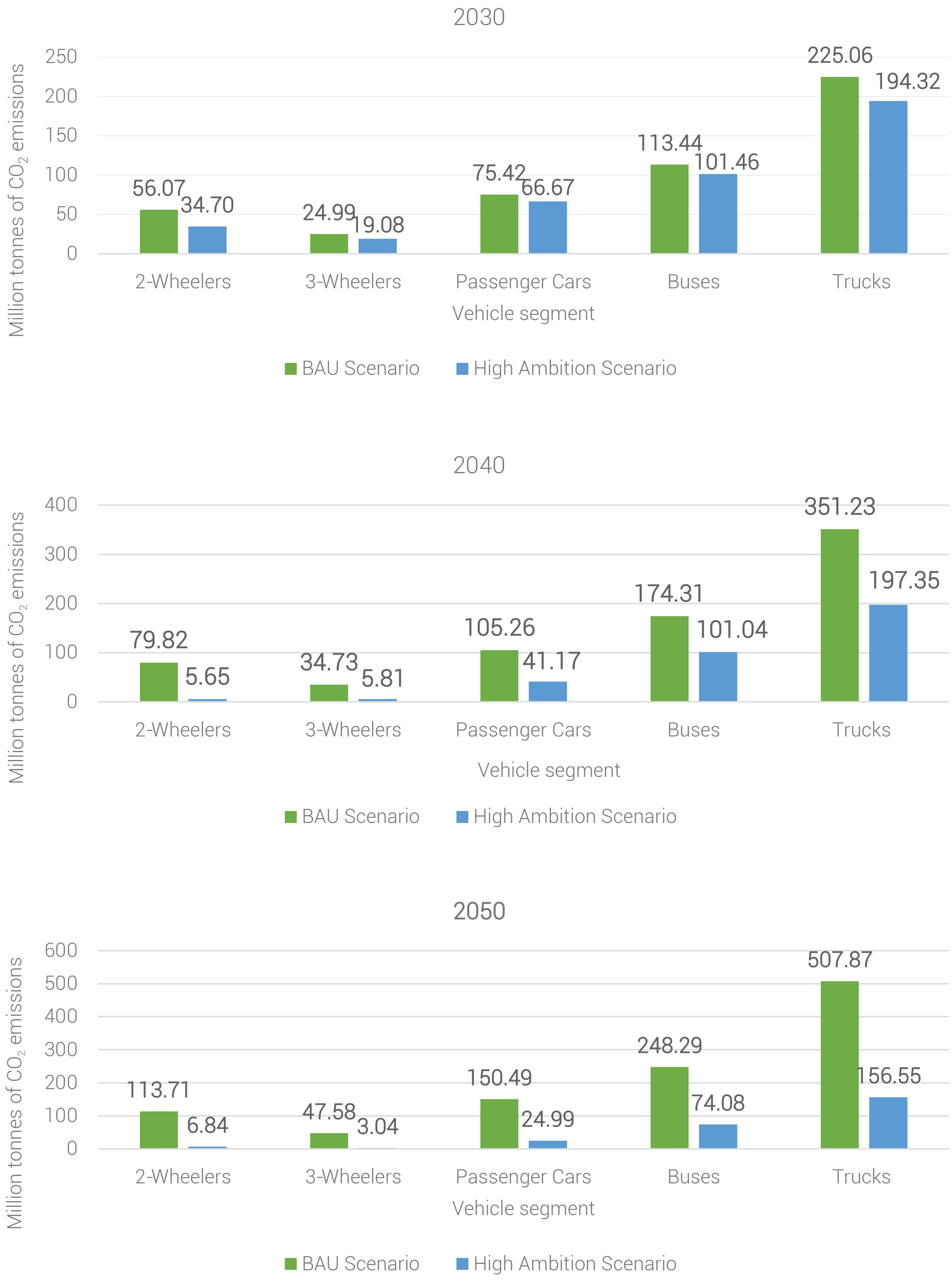


Figure 13: Scenario-based variations in emission intensity of road-transport vehicle segments in the coming decades

Passenger vs freight: Emission intensity when observed for modal share between freight and passenger use-cases for the scenarios in consideration yield observations as illustrated in Figure 14. While the emission contribution is mostly equal under the BAU scenario, it is expected that the high ambition scenario primarily will impact the passenger vehicles. Thus, a corresponding shift in emission quantum weighing towards freight vehicles is seen by 2050.

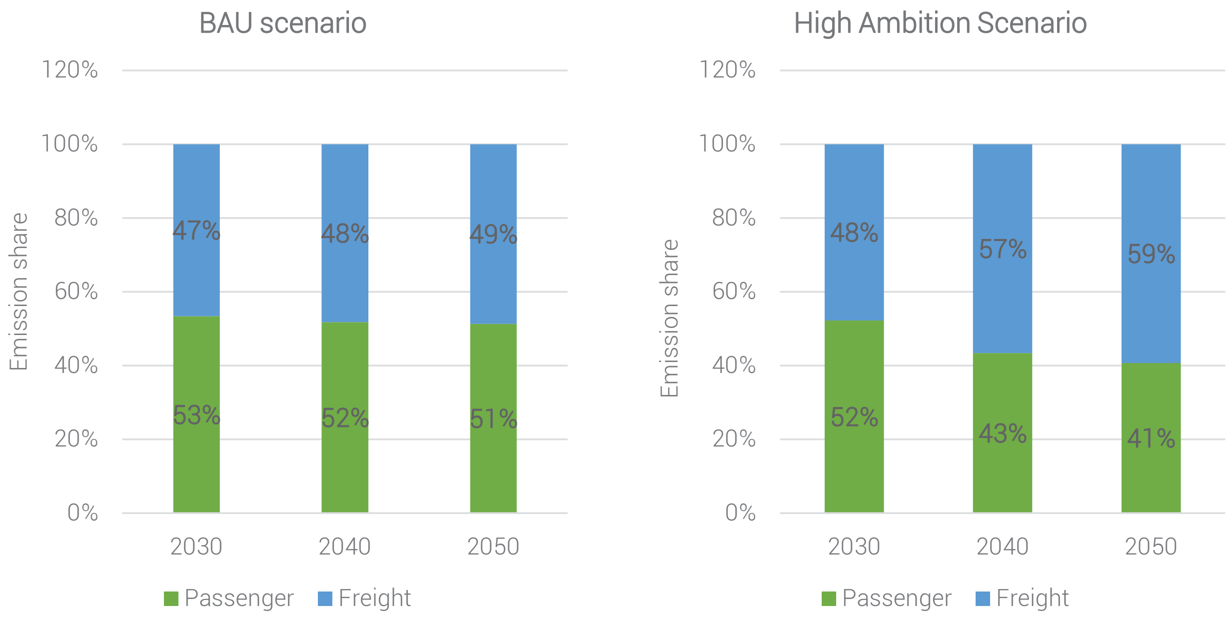
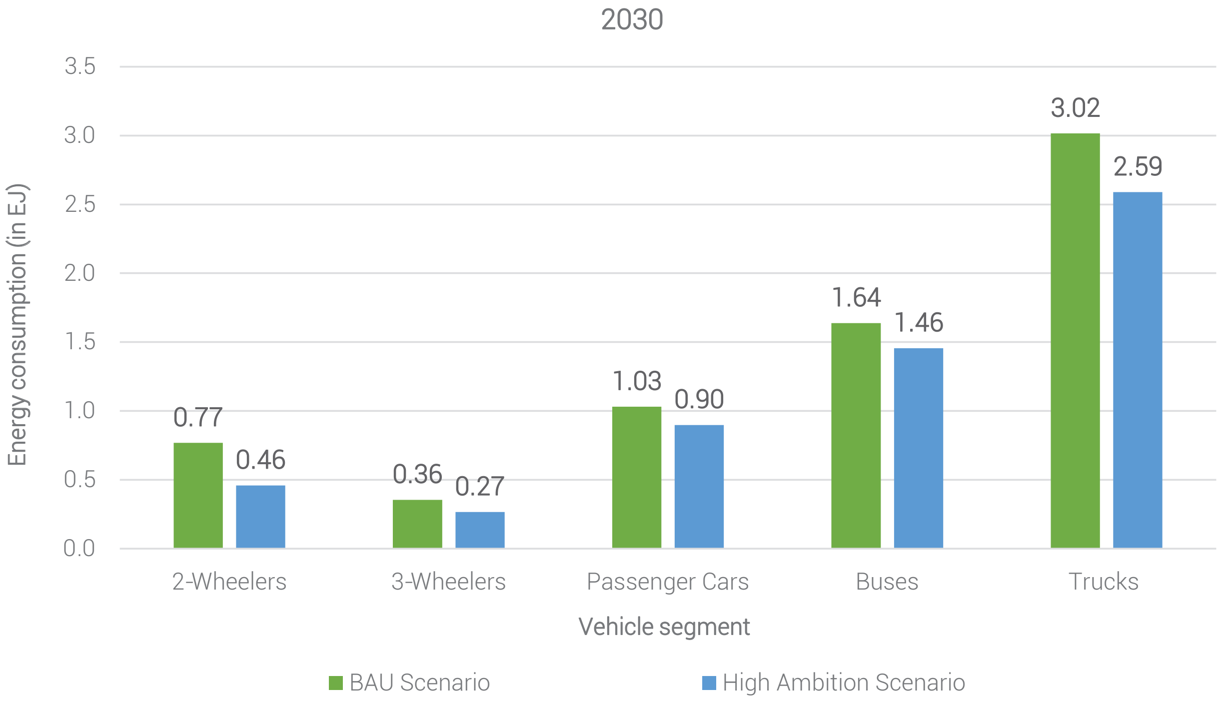


Figure 14: Share of emission intensity between passenger and freight use-cases in road transport

Energy consumption by vehicle segment: With the BAU scenario and high-ambition scenario remaining same as described in the previous section, we observe projections across decades leading to 2050 as shown in Figure 15. As expected, the BAU scenario results in an increasing trend of energy consumption across all vehicle segments up to 2050. Significant jumps in energy consumption by 2050 can be observed for the buses and trucks segments with an increase by over 300 percent compared with 2020 levels.

Contrasting to the trends with emission intensity, in the high-ambition scenario, it is observed that all vehicle segments, barring buses, have a projected decrease in energy consumption as compared with 2020 levels. In the case of buses, the energy consumption for this segment peaks in the decade up to 2030, and then sees a lower, but steady trend in energy consumption up to 2050. A similar trend is noticed for the truck segment which peaks in 2030, and then sees a drop in energy consumption. However, compared to 2020 levels the trucks segment sees a decrease in energy consumption by 12.35 percent.



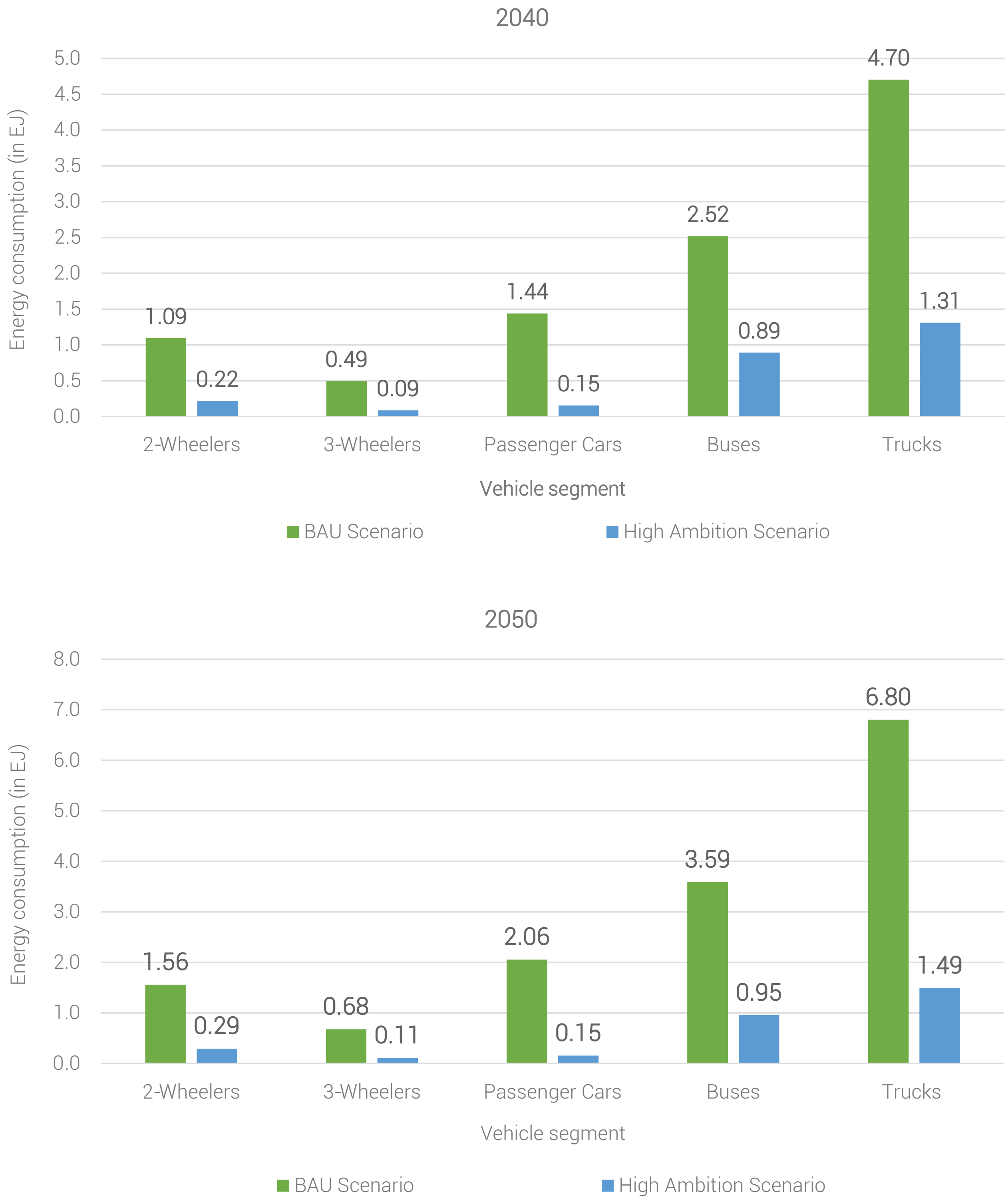
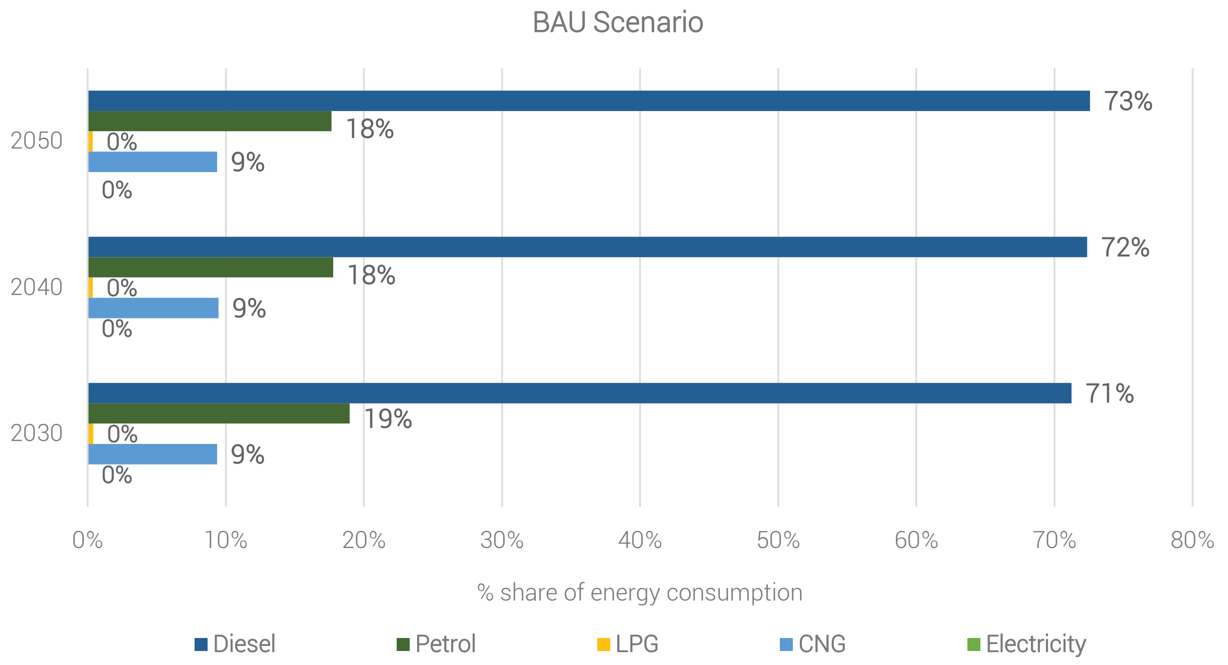


Figure 15: Scenario-based variations in energy consumption of road-transport vehicle segments in the coming decades

Energy consumption by fuel type: Under the BAU scenario, the percentage share of vehicles segmented according to their fuel type follows a fairly constant trend with minor changes from the percentage share by fuel type observed in 2020. Diesel continues to remain the most consumed fuel with a 73 percent share in 2050, and EVs form a miniscule share (0.01 percent) of the on-road vehicles. However, as observed in Figure 16, the high-ambition scenario has a reversal in the dominant fuel type. EVs hold the majority share of on-road presence with almost 67 percent by 2050. Diesel vehicles are observed to reduce by almost 60 percent as compared with their on-road share in 2020.



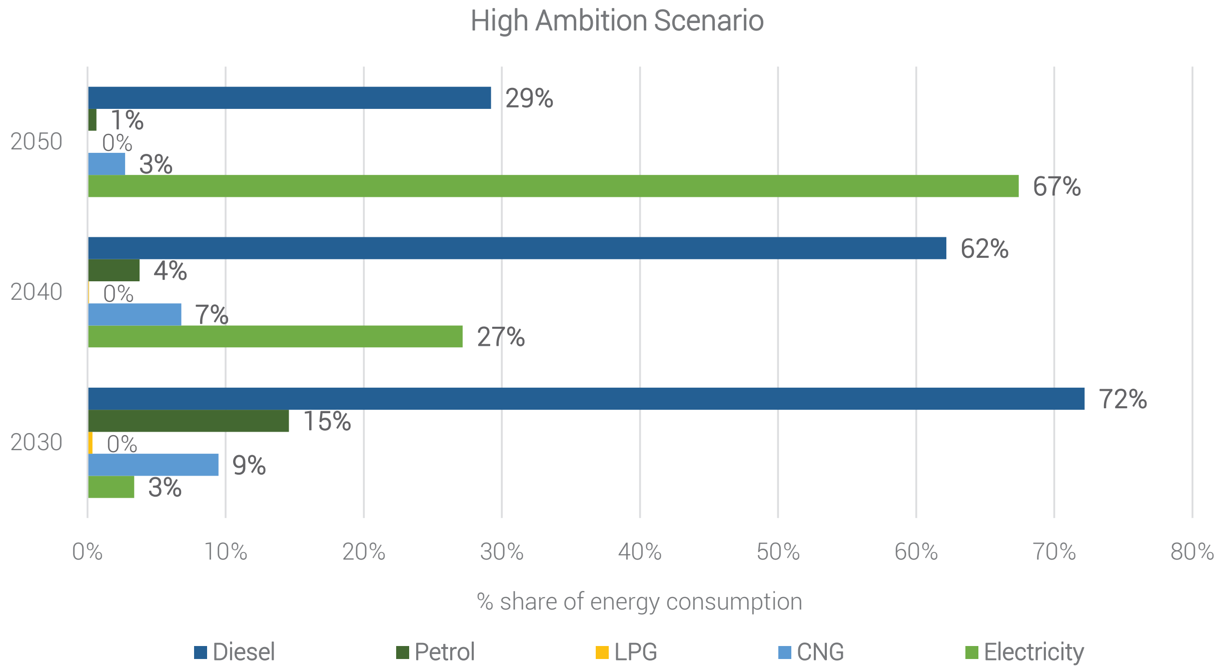


Figure 16: Scenario-based projections for percentage share of on-road vehicles by fuel-type

MARITIME

Forecasts by the IMO indicate that maritime trade is expected to see an increase between 40 – 115 percent by 2050 in comparison to 2020 levels[56]. Given that the energy demand in this sector is met by fossil fuels, lack of effective decarbonisation policies is bound to increase the GHG emissions. The IMO predicts an increase between 50 - 250 percent by 2050 in comparison to 2020 GHG emission levels[47].

---

[56] chrome-extension://efaidnbmnnnibpcajpcglclefindmkaj/https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2021/Oct/IRENA_Decarbonising_Shipping_2021.pdf

A study by the International Renewable Energy Agency (IRENA), defined four energy scenarios (Years 2018 - 2050) for the global maritime sector – Base Energy Scenario (BES), Planned Energy Scenario (PES), Transforming Energy Scenario (TES), and the 1.5°C Scenario (1.5-S). Based on the long-term projections provided in the IMO GHG study[57], the scenarios were defined as mentioned in Table 4.

Table 4: Maritime global energy scenarios 2050[47]

Scenario	Description
BES	Technological development and concomitant socio-economic progress are derived from fossil fuels such as Heavy Fuel Oil (HFO), which continue to be the primary fuel source by 2050. The future energy demand and supply follow historical trends and Energy Efficiency (EE) measures are absent.
PES	Partial implementation of decarbonisation measures including EE. Primary fuels such as HFO and Very Low Sulphur Fuel Oil (VLSFO) are displaced by LNG.
TES	Decarbonisation ambitions are higher and EE measures are implemented to a large extent. LNG is the primary fuel and is supplemented by advanced biofuels.
1.5-S	Deep decarbonisation strategy adopted. Energy intensity levels see considerable improvement. Green hydrogen-based fuels displace fossil fuel usage.

Assuming that the global scenarios trends prevail in India, the expected future scenario on the facets of fuel consumption[58] and CO_2 emissions are described below-

Fuel Consumption Projections: The business-as-usual trend represented by BES predicts a 30 percent increase in fuel demand compared with 2018 levels[47]. In PES, owing to the partial adoption of decarbonisation measures, a dip in projected fuel demand compared with BES is expected by 2050, where a 24 percent increase is predicted from 2018 levels[47]. The TES and 1.5-S where ambitious decarbonisation policies are presumed to have been adopted, a decrease in fuel demand is observed compared with 2018 levels. TES and 1.5-S project a decrease of three percent and 17 percent respectively[47].

Keeping with this trend, the expected fuel demand projections for India are represented in Figure 17. Assuming 2019 as the base year, the fuel consumption in 2050 is expected to be around 2.13 trillion tonnes of fuel in the BES scenario. Alternatively, when deep decarbonisation strategies have been adopted to align with the 1.5°C scenario, fuel consumption is reduced from current levels to 1.3 trillion tonnes of fuel.

---

[57] https://www.imo.org/en/OurWork/Environment/Pages/Fourth-IMO-Greenhouse-Gas-Study-2020.aspx

[58] The energy demand is assumed to be proportionate to the fuel consumed in alignment with IRENA standards where fuel consumption is directly linked to vessel's energy demand. (See Table 1, 'A Pathway to Decarbonise the Shipping Sector by 2050', IRENA 2021)

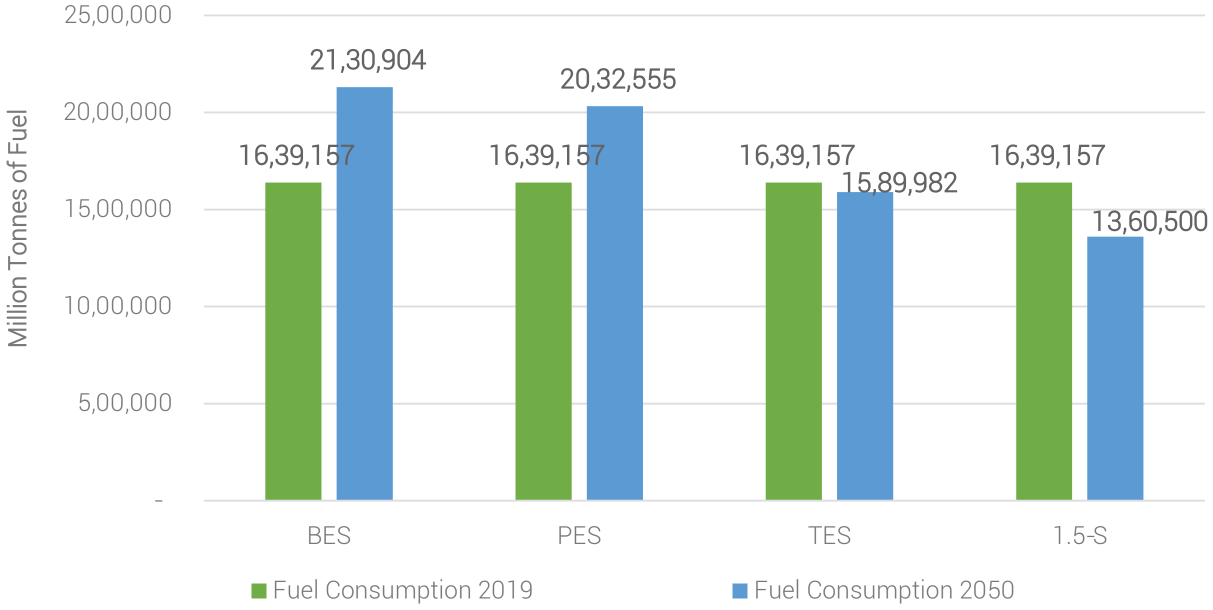


Figure 17: Scenario-based fuel consumption projections for maritime sector in India in 2050[14,47]

CO_2 Emissions: Projections for carbon emissions have an upward trend, as expected, in the business-as-usual scenario. In PES, where LNG is the primary fuel, we observe the carbon emissions remain on similar levels as 2019, with a slight reduction of around 0.53 percent[59]. As observed with fuel consumption trends, the TES and 1.5-S pathways result in significant reduction in carbon emissions as observed in Figure 18. A 50 percent reduction is projected in TES and around 80.8 percent reduction in CO_2 emissions is projected in 1.5-S by 2050[50].

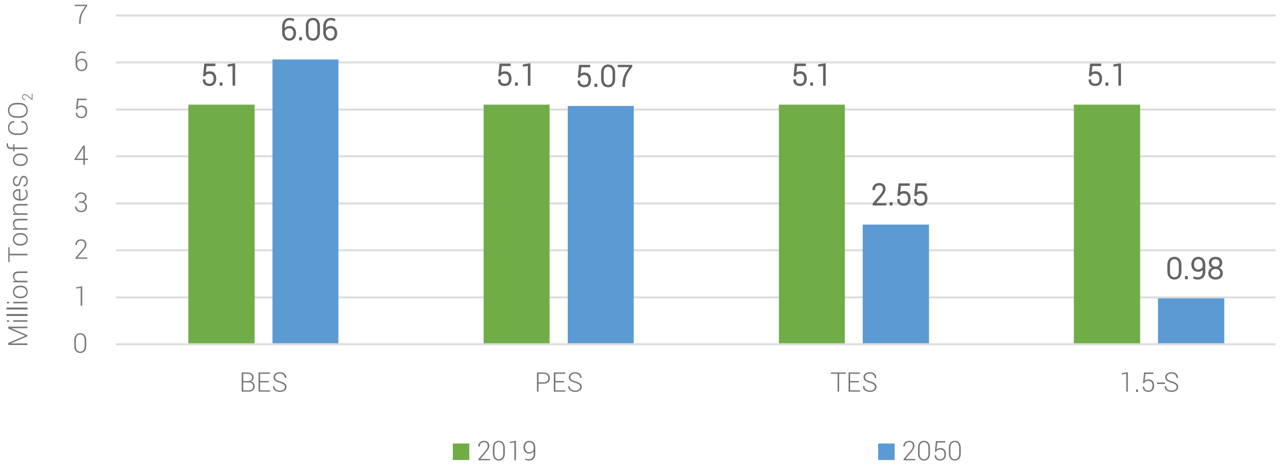


Figure 18: Scenario-based CO_2 emission for maritime sector in India in 2050[14,47].

AVIATION

Globally, aviation is a major contributor to GHG emissions. In FY 2017-18, aviation turbine fuel consumption stood at 7.6 million tonnes[16] in India, and is expected to see an upward trend in the coming years with an estimate of 8 million tonnes by 2030[60]. The fuel consumption relayed CO_2 emissions of about 12.3 million

---

59 Vasudha analysis from report - chrome-extension://efaidnbmnnnibpcajpcglclefindmkaj/https://www.irena.org/-/media/Files/IRENA Agency/Publication/2021/Oct/IRENA_Decarbonising_Shipping_2021.pdf?rev=b5dfda5f69e741a4970680a5ced1ac1e

60 chrome-extension://efaidnbmnnnibpcajpcglclefindmkaj/https://www3.weforum.org/docs/WEF_Clean_Skies_for_Tomorrow_India_Report_2021.pdf

tonnes in 2018. With the sector expected to see a high growth trajectory, the emissions are also expected to grow proportionately.

According to the Sustainable Alternative Futures for India (SAFARI) model, the GHG emissions from the aviation sector (freight included) is estimated to increase by 3.6 times in 2030[46], and increase by about 12.6 times by 2050[46] when compared with 2018 levels. As observed in Figure 19, we see that the CO_2 emissions is expected to grow to 44.31[4] million tonnes of CO_2 by 2030, and about 155.07[4] million tonnes of CO_2 by 2050.

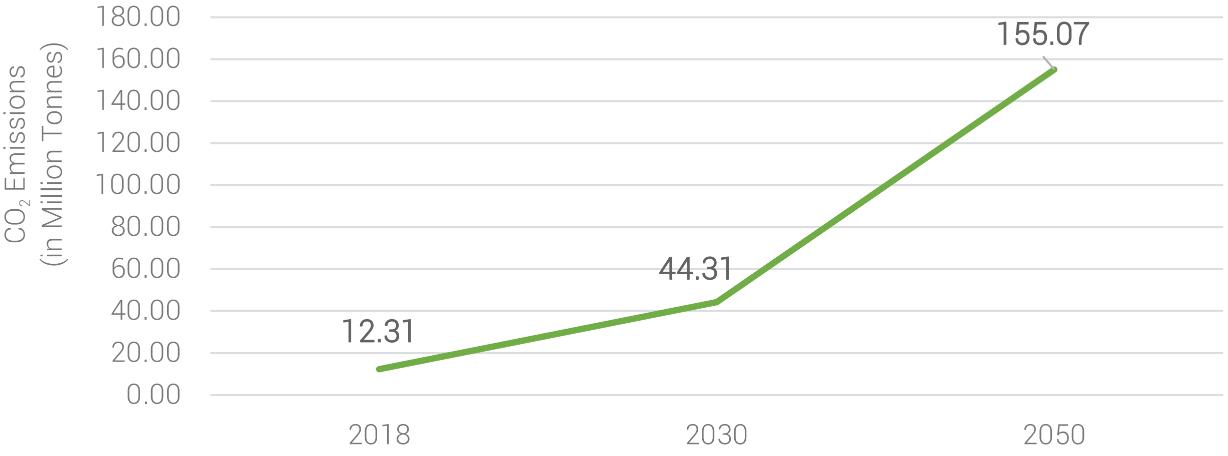


Figure 19: Projections for GHG emissions in the aviation sector[46]

RAILWAYS

Indian Railways have adopted multiple strategies to reduce its carbon footprint apart from electrification of its routes, such as development of dedicated freight corridors, and introducing green certification for their establishments. By 2029-30, a total of 30 GW[61] of renewable capacity is expected to be installed by the Indian Railways to support its energy requirements. The Railways is on course to complete 100 percent electrification of its broad-gauge network and with that the electricity requirement is expected to increase by 70.83 percent to 72 BU in 2029-30 from 21 BU in 2021-22[52]. Further, by 2050, the passenger demand (in millions per year) and freight demand (in million tonnes) are expected to increase by 51.42 percent and 69.78 percent respectively[62].

---

[61] https://pib.gov.in/PressReleasePage.aspx?PRID=1865754

[62] chrome-extension://efaidnbmnnnibpcajpcglclefindmkaj/https://indianrailways.gov.in/NRP%2015th%20DEC.pdf

5

TOTAL COST OF OWNERSHIP FOR TRANSPORT

CLEAN-POWERED VEHICLES VS FOSSIL-FUEL COUNTERPARTS

While the decarbonisation narrative for the transport sector places electrification as a viable strategy, the transition to EVs further requires tangible factors to nudge the shift amongst its stakeholders. The Total Cost of Ownership (TCO) is a valuable metric to expound on the economic superiority of EVs over their fossil-fuel-based counterparts. By accommodating the total costs associated with the vehicle from purchase to other accumulated costs over the lifetime of the vehicle, the TCO presents a concrete measure of the economic efficiency of the vehicles. The analysis included in this report has been restricted to road transport due to the paucity of sustainable or electrified operational alternatives for the aviation and maritime sector.

SCOPE OF ANALYSIS

The TCO was calculated across vehicle segments in road transport for values corresponding with the year - 2022. In each vehicle segment, the TCO was calculated separately based on the fuel types applicable. In the four-wheeler vehicle segment, a separate analysis was done for the transport (taxis) and non-transport (personal-use) categories. The four-wheelers were branched into sub-segments based on vehicle cost. The average daily kilometres driven in two-wheeler, and four-wheeler segments is considered as 30 km. Further, the bus segment was categorised based on bus length, subsidy provision (for E-bus), and use of air-conditioning. Table 5 describes the vehicles considered for TCO comparison. The life of vehicles (except buses) considered for the TCO analysis has been mentioned in accordance with the Companies Act, 2013. For buses, the useful life has been considered as 10 years across all its sub-categories[63].

Table 5: Vehicle categories considered for TCO analysis

Vehicle Segment	Useful Life (in years)	Fuel Type	Sub-categories
2-wheeler	10	Petrol	-
		EV	-
3-wheeler	6	CNG	-
		EV	-
4-wheeler (private cars)	8	Petrol	Low-Cost
			Medium-Cost
			Luxury
		EV	Low-Cost
			Medium-Cost
			Luxury

---

[63] https://indianexpress.com/article/india/india-news-india/90-best-buses-past-age-limit-3740787/

Vehicle Segment	Useful Life (in years)	Fuel Type	Sub-categories
4-wheeler (Taxis)	6	CNG	-
		EV	-
Bus	10	Fossil Fuel	ICE Bus (12 m) (AC)
			ICE Bus (9 m) (AC)
			ICE Bus (12 m) (Non-AC)
			ICE Bus (9 m) (Non-AC)
		Electric	E-Bus (12 m) (AC + W/o Subsidy)
			E-Bus (9 m) (AC + W/o Subsidy)
			E-Bus (12 m) (Non-AC + W/o Subsidy)
			E-Bus (9 m) (Non-AC + W/o Subsidy)
			E-Bus (12 m) (AC + With Subsidy)
			E-Bus (9 m) (AC + With Subsidy)
			E-Bus (12 m) (Non-AC + With Subsidy)
			E-Bus (9 m) (Non-AC + With Subsidy)

The data used in calculating the TCO has been furnished in Annexure. A few overarching assumptions have been considered across the vehicle segments as mentioned below-

On the aspect of vehicle purchase, 30 percent of the vehicle cost has been considered as a down-payment, while the remaining 70 percent is assumed to be financed via loans. The interest rate of the loan is assumed to be 10 percent with a tenure of 5 years.

Based on the fuel type, certain assumptions were considered across all vehicle segments as mentioned in Table 6.

Table 6: Overarching assumptions based on type of fuel

Fuel Type	Fuel Cost	Depreciation rate of vehicle (in %)[64]
Petrol	₹100/litre	10.40
Diesel	₹80/litre	10
CNG	₹60/kg	10
EV	₹4.5/kWh	13.90

The final analysis consolidates the TCO over the life of the vehicle and the subsequent TCO/km for each of the sub-categories mentioned in Table 5. Further, insights into the expected duration to achieve TCO parity within the respective vehicle segments have also been probed.

TWO-WHEELER

Brief on Analysis: Petrol and Electricity are the fuel-types considered for TCO comparison. The annual depreciation rates for the two-wheeler segment are retained as mentioned in Table 6. The battery capacity of electric two-wheelers is 20 times[64] lower than their four-wheeler counterparts. The fuel-cost for charging a two-wheeler is thus assumed to be ₹10/charge-cycle. The data for ex-showroom price, mileage, and other input parameters as showcased in the Annexure, is derived by averaging the corresponding parameters of the existing on-road vehicle models for the respective fuel types.

TCO Result: As observed in Figure 20, the TCO for the electric two-wheeler is almost 70 percent lower compared with its petrol counterpart and has surpassed TCO parity between the two fuel types. On average, the TCO/km for petrol vehicles is more than three times that of electric two-wheelers.

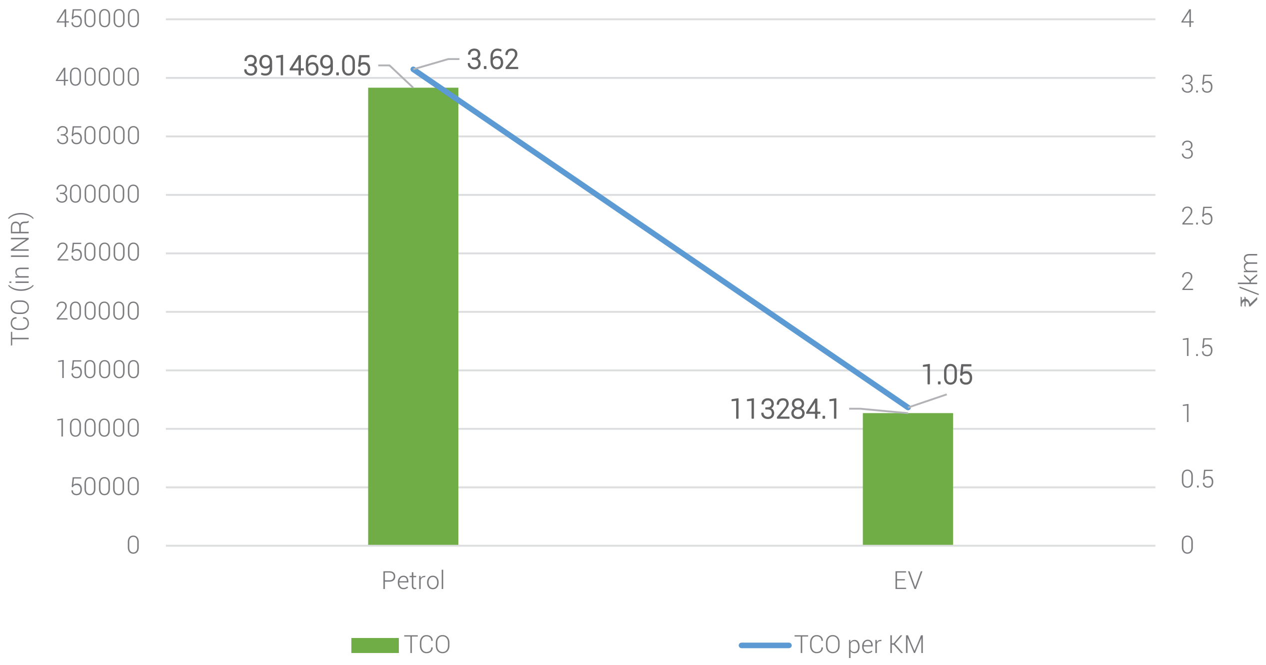


Figure 20: TCO comparison for two-wheeler segment (India)

THREE-WHEELER

Brief on Analysis: CNG and Electric three-wheeler vehicles used for passenger applications have been considered for the TCO analysis. On average, the daily distance travelled by three-wheelers is assumed to be 55 km[65]. The attributes concerning maintenance and insurance were derived from secondary sources for the State of Delhi[66]. The ex-showroom prices were based on specific models for CNG and EV – Bajaj RE CNG, and Mahindra Treo, respectively.

TCO Result: As observed in Figure 21, we observe that TCO parity has been achieved in the three-wheeler segment. The TCO for EVs are 30 percent lower when compared with its CNG alternative. The difference is more prominent when comparing the running costs. EVs are cheaper by about 44 percent when compared with CNG three-wheelers on a TCO/km basis.

---

[64] chrome-extension://efaidnbmnnnibpcajpcglclefindmkaj/https://theicct.org/wp-content/uploads/2021/12/E2W-cost-2030-India-jul2021.pdf

[65] https://www.researchgate.net/publication/344204048_Total_Cost_of_Ownership_Analysis_of_the_Impact_of_Vehicle_Usage_on_the_Economic_Viability_of_Electric_Vehicles_in_India

[66] https://www.teriin.org/project/roadmap-electrification-urban-freight-india

Figure 21: TCO comparison for three-wheeler segment (India)

FOUR-WHEELER

Brief on Analysis: The four-wheeler segment was analysed separately for private cars and taxis, owing to the vastly differing operating conditions. Under the ambit of private cars, three categories were defined on the basis of vehicle cost for Petrol and Electricity fuel type as described in Table 5. Specific car models were chosen in each segment subject to availability of Internal Combustion Engine (ICE) and EV versions of the same model. Under each category of four-wheeler, the attributes concerning the parameters for TCO such as the ex-showroom price, costs towards insurance and maintenance, and registration tax were derived from secondary research corresponding to the specific car models in the respective segments. Subsidy provision has been considered for the EV models. The final input values have been detailed in the Annexure.

Further, for taxis owing to different operating conditions, the life of the vehicle has been considered as six years. CNG has been considered the primary fossil-fuel-powering Taxi fleets and they have been analysed for the Tata Tigor model. For EVs, correspondingly, the Tata Tigor EV model has been considered for the analysis. The average distance covered by taxis in a day is assumed to be 190 km[65].

TCO Result: In the private car segment, as observed in Figure 22, the TCO of EV is currently higher across all segments in consideration. However, with a subsidy provision of INR 1,50,000 per vehicle, we observe that for the low-cost and medium-cost segments, TCO parity has been achieved for EVs. In the low-cost private car segment, we observe that without subsidy provision, the TCO of EVs are higher by 5.4 percent compared to its petrol counterpart. Similarly, in the medium-cost segment, the TCO of EV (without subsidy provision) is currently higher by 6.5 percent compared to its petrol counterpart. In the luxury car segment, we observe that EVs (with and without subsidy) are higher in their TCO value compared with their petrol counterpart. The TCO of EV (without subsidy) is currently higher by ~41 percent compared to its petrol counterpart.

Figure 22: TCO comparison for four-wheeler private car segment (India)

Four-wheeler taxis have higher usage and thereby a reduced useful life. Taking these considerations into account, the TCO was compared for CNG vehicles and EVs as observed in Figure 23. EVs have much lower operating costs and thus result in TCO that is about 31 percent lesser than its CNG counterpart.

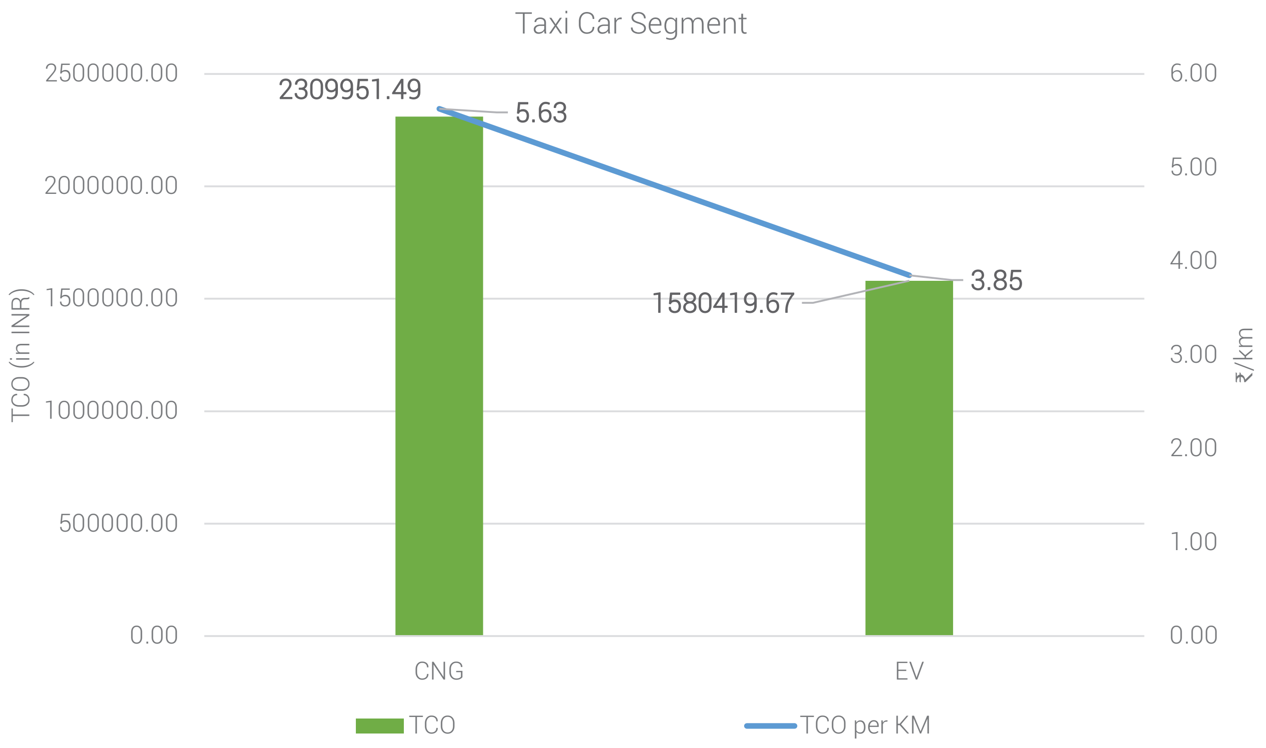


Figure 23: TCO comparison for four-wheeler taxis (India)

BUSES AND TRUCKS

Brief on Analysis: Buses were assumed to possess a useful life of 10 years. Broadly two vehicle fuel types – Fossil fuel and Electricity, were considered, and both fuel types were further branched based on the bus lengths – 9m and 12m. The fossil fuel-based buses were further grouped on the basis of air-conditioning (AC) use to form four sub-categories as shown in Table 5. The electric buses were considered with another parameter of subsidy provision, in addition to bus length, and AC use, to render eight sub-categories as seen in Table 5. For the trucks segment, a brief on TCO comparison has been captured in Box 1.

A TCO comparison across the bus sub-categories was carried out. Depending on the electricity consumed per kilometre of travel, there is a significant impact on the vehicle's TCO. Based on this understanding, a sensitivity analysis for the segments rendering the lowest TCO values was conducted by varying the vehicle efficiency to showcase the impact on the TCO of the vehicle.

TCO Result: E-buses outperform their ICE counterparts in all the sub-categories as observed in Figure 24. The TCO/km for E-bus ranged from ₹41.47 to ₹62.25, for the 9m bus length. The ICE counterpart for the 9m bus had a TCO/km range of ₹64.94 to ₹76.69. In the 12m bus length segments the TCO/km for E-buses ranged from ₹45.46 to ₹63.29. The ICE counterpart for the 12m bus had a TCO/km range of ₹71.99 to ₹84.79. Thus, it is clear that TCO parity has been achieved for the bus segment, and builds a strong case for transition to electric counterparts.

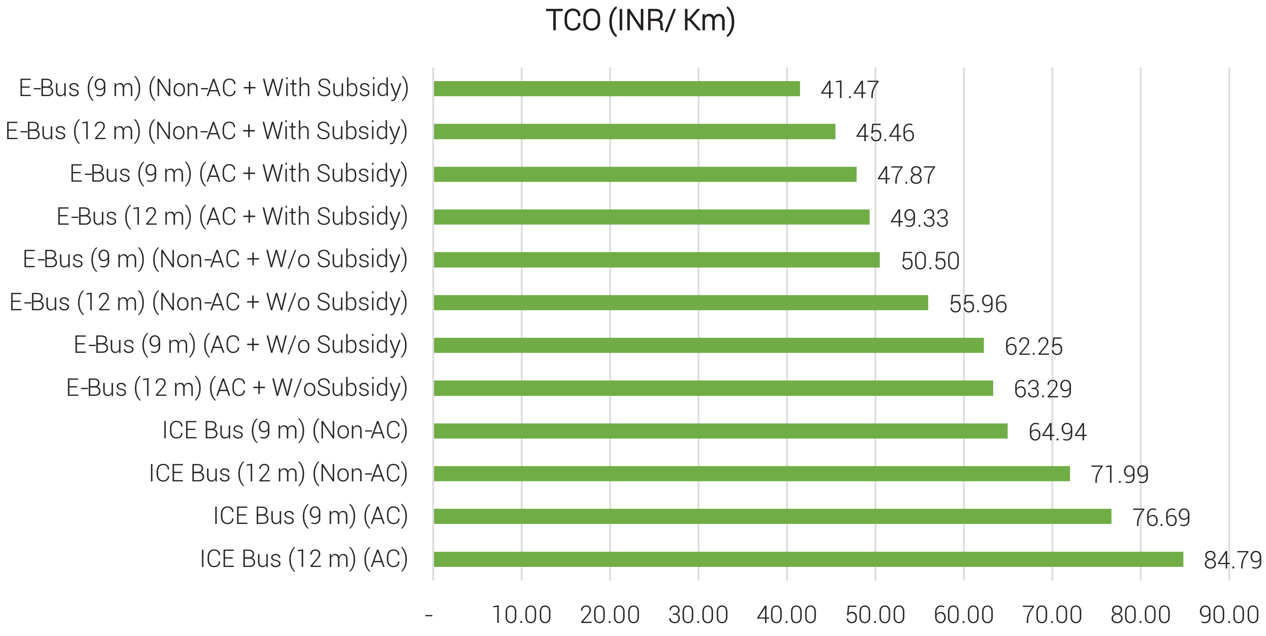


Figure 24: TCO/km comparison for Bus segments

Further, the TCO of the vehicles is expected to improve significantly with the rapid pace of technological advancements in battery technology, which render higher efficiencies. To demonstrate the same, a sensitivity analysis as illustrated in Figure 25 showcases how minor vehicle efficiency improvements can significantly affect the TCO/km. The e-bus sub-category of non-AC combined with subsidy, and non-AC combined without subsidy is considered for the analysis. It can be observed that with a 0.4kWh improvement per km, there is a 6.31 percent decrease in TCO for E-bus (9m, non-AC, and with Subsidy) and 6.51 percent decrease in TCO for E-bus (9m, non-AC, and without subsidy).

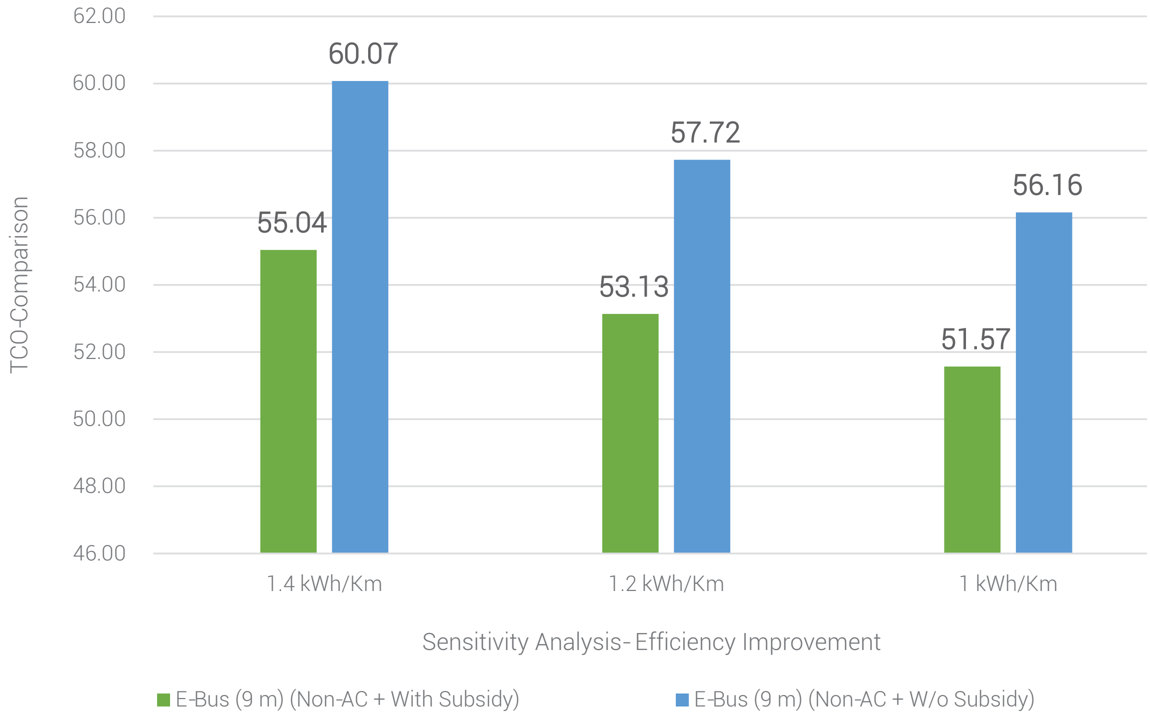


Figure 25: Sensitivity analysis of TCO/km by varying vehicle efficiency of E-bus

Box 1: TCO Comparison of truck segments

A study conducted under the aegis of NITI Aayog sought to assess the economic feasibility of transitioning to zero emission trucks (ZETs) under a mature production scenario, i.e. with a dedicated production facility that will lead to reasonable scale and a competitive market price[67]. Three fuel types were considered-diesel, battery electric, and hydrogen fuel-cell renewable. Four different use cases for freight trucking in India were identified and the corresponding TCO analysis[64] can be observed in the table below:

	Case I	Case II	Case III	Case IV
Description	**Medium-Duty Trucks (MDTs) for short interstate movement**	**MDTs for regional haul**	**Heavy-Duty Trucks (HDTs) for regional haul**	**HDTs for long haul**
Battery Size (kWh)	80	150	470	1050
Weight (tonnes)	12	12	31	31
Distance Range (km)	100-150	200-300	200-300	>500
TCO per km for diesel (INR/km)	~16	~14	~31	~31
TCO per km for electric (INR/km)	~14	~12	~36	~49
TCO per km for hydrogen fuel cell-renewable (INR/km)[68]	~24	~21	~46.5	~46.5
TCO Parity Year (for electric)	Reached under the scenario	Reached under the scenario	~2024	~2026
TCO Parity Year (for hydrogen fuel cell-renewable)[66]	2028	2028	Beyond 2030	Beyond 2030

The analysis shows that the TCO for Battery-electric medium duty trucks (MDTs) for Case I and Case II is already cheaper than their diesel counterparts by ~12 percent and ~16 percent respectively. This is largely due to the low operating costs which compensates the initial capital cost of a battery-electric truck over a smaller distance and battery size. Thus, delivery trucks and small trucks for regional haul are ideal for transitioning to electric alternatives.

The upfront capital cost of electric heavy duty trucks (HDTs) for longer distances is much higher than their diesel counterparts. Consequently, the TCO for electric HDTs as of today is ~3.7 and ~6.6 times higher than their diesel variants for Cases III and IV respectively. Despite this, the high operational savings provided by electric HDTs (~INR 18/ km for case III & ~INR 36/ km for case IV), means that TCO parity will be reached by ~2024 and ~2026 for cases III & IV respectively.

When observed for hydrogen fuel cell trucks powered from renewable sources, we see that the TCO is favourable to diesel trucks. For both MDTs and HDTs, the TCO/km is about 50 percent higher than that of its diesel counterparts. TCO parity for MDTs is expected to be reached by 2028, and diesel HDTs are expected to remain more economical than hydrogen fuel-cell (renewable) trucks by 2030. However, studies have shown that hydrogen-powered trucks are bound to be the better option than battery-electric over longer distances versus a diesel equivalent[69] owing to characteristics such as similar operation as battery-electric alternatives whilst having faster refuelling times.

---

[67] NITI Aayog and RMI. (September 2022). *Transforming Trucking In India: Pathways to Zero Emission Truck Deployment.* https://rmi.org/insight/transforming-trucking-in-india/

[68] https://www.researchgate.net/figure/Total-cost-of-ownership-for-diesel-electric-and-hydrogen-fuel-cell-long-haul_fig7_335104931

[69] Hall, W., Spencer, T., Renjith, G., and Dayal, S. 2020. *The Potential Role of Hydrogen in India: A pathway for scaling-up low carbon hydrogen across the economy.* New Delhi: The Energy and Resources Institute (TERI). https://www.teriin.org/sites/default/files/2021-07/Report_on_The_Potential_Role_of_%20Hydrogen_in_India.pdf

6

ASSESSING MAJOR SECTORAL PARAMETERS

Assessing investment and job numbers are key to understanding the impact on various important facets, such as:

- **Economic growth**: Investment and job numbers are key indicators of economic growth. By assessing these numbers, policymakers and investors can identify opportunities to promote sustainable economic growth through transportation infrastructure investment and job creation.
- **Innovation and competitiveness**: Investment and job numbers can also provide insights into the level of innovation and competitiveness in the transport sector. For example, a high level of investment in research and development can indicate a focus on innovation, while a high number of jobs in the sector can indicate a strong talent pool and a competitive industry.
- **Environmental sustainability**: Investment and job numbers can also be used to evaluate the environmental sustainability of the transport sector. For example, a high level of investment in electric vehicles and other clean transportation technologies can indicate a commitment to reducing greenhouse gas emissions and mitigating the impacts of climate change.
- **Equity and social justice**: Investment and job numbers can also be used to assess the equity and social justice implications of transportation infrastructure investment. For example, a focus on creating jobs in underserved communities can help reduce economic inequality and promote social justice.

INVESTMENT ESTIMATES

The investments in the EV industry are expected to fall between USD $ 150 billion to USD $ 266 billion.[70] In addition, it is also expected that the EV industry will attract foreign direct investments (FDIs) to the tune of USD $ 20 billion by 2030.[71] The projections are made based on several assumptions and thus vary in terms of the quantum, including equipment cost and vehicle sales as well as the investments required to augment the charging infrastructure in tandem with the EV penetration in the market. Table 7 captures the snapshot of the reports that have quantified the total investments needed in the EV space by 2030.

Table 7: EV Investments 2030

Sr. No.	Report	Amount	Assumptions	Source
1	Investor Perspectives on Accelerating Growth in the Indian EV Ecosystem	USD $ 150 billion by 2030	This projection comes from a secondary source in this report. (Invest India 2022) 'Electric Mobility Sector'. Presentation at the Stakeholder Roundtable on Understanding Investment Opportunities, Barriers, and Priorities for a Globally Competitive EV Manufacturing Sector in India, New Delhi, India, February 15, 2022	india-evs-report-v3.pdf (etn.news)

---

[70] india-evs-report-v3.pdf (etn.news) and https://www.ceew.in/cef/solutions-factory/publications/CEEW-CEF-financing-india-transition-to-electric-vehicles.pdf

[71] https://www.adlittle.com/en/insights/report/unlocking-india%E2%80%99s-electric-mobility-potential

Sr. No.	Report	Amount	Assumptions	Source
2	Financing India's Transition to Electric Vehicles: A USD 206 Billion Market Opportunity (FY21 - FY30)	Cumulative investments required will be USD $ 206 billion (INR 14,42,400 crore) till FY 2030	The investments are estimated from sales perspective i.e. the amount that consumers will need to spend (Sale of ~102 million EV units till FY 2030) - includes commercial and private cars, buses, 3-wheelers and 2-wheelers. On the other hand, it is estimated that USD $ 180 billion (INR 12,50,000 crore) will be required for vehicle production and initial investment required for charging infrastructure – Charging infrastructure for buses is not included.	https://www.ceew.in/cef/solutions-factory/publications/CEEW-CEF-financing-india-transition-to-electric-vehicles.pdf
3	Powered by Power The EV Industry in India	EVs will contribute USD $ 150 billion by 2030 to India's GDP	No assumptions listed – the projections are based on an estimated CAGR of ~90 percent in vehicle sales	https://rbsa.in/powered-by-power-the-ev-industry-in-india/
4	Mobilising Finance for EVs in India: A Toolkit of Solutions to Mitigate Risks and Address Market Barriers	INR 19.7 lakh crore (USD $ 266 billion) between 2020 and 2030	These estimations are based on cumulative capital cost of vehicles, electric vehicle supply equipment (EVSE) hardware, and batteries (including replacements) covering the 2020-2030 timeframe. The projections are based on existing analysis of future passenger- and freight-vehicle sales. It is assumed that by 2030 weighted average EV sales penetration across segments can potentially be about 70 percent. The assessment has been made on the bases of expert interviews and forecasted cost competitiveness. This report also estimates that the annual EV finance market will be INR3.7 lakh crore (USD50 billion) in 2030.	https://rmi-india.org/insight/mobilising-finance-for-evs-in-india/

JOB ESTIMATES

As the EV sector is poised to grow exponentially in the coming years, employment opportunities will also surge. By 2030, the EV industry can create one crore direct jobs and five crore indirect jobs, as per an estimate by the Ministry of Skill Development and Entrepreneurship.[72] The sector is already witnessing talent gaps, signifying the need to attract talent pools by both, the local manufacturing value chain and international entities foraying into India.[73] The companies are focused on building a talent base for top leadership as well as technical skill pools with employment growing at a significant pace by over 108 percent in the last two years.[74]

---

[72] https://www.ey.com/en_in/automotive-transportation/electrifying-indian-mobility-accelerating-the-pace-of-electric-mobility

[73] https://energy.economictimes.indiatimes.com/news/power/ev-industry-in-india-battles-high-attrition-amid-demand-for-talent/98260516

[74] Latest Employment Trends in EV Sector 2022 Report (cielhr.com)

7

CONCLUSION

Across the transport sector, the future scenarios for emission intensity and fuel consumption indicate a unanimous rise. Adoption of energy efficiency measures potentially curtail the net growth in emissions, however for reduction in emissions, there is an impendent need to adopt electrification measures either directly or indirectly.

Concerning road transport, global best practices indicate two front-runners for decarbonisation through electrification - electric vehicles and hydrogen fuel-cell vehicles. For the passenger travel segments, we observe that commercially viable technologies exist with some vehicle segments already achieving TCO parity of their electric alternatives against their fossil-fuel counterparts. The two-wheeler segment which occupies over 70 percent share in on-road presence, has an EV alternative that has a TCO that is almost 70 percent lesser than its fossil-fuel counterpart. Similar trends are observed for buses, where the E-bus has breached TCO parity when gauged against its diesel counterpart, across multiple segments and operating conditions. The four-wheeler EV segment has achieved TCO parity in a few segments and has also seen an increase in its uptake owing to commercial viability. In the five year period from FY 2017-18 to FY 2022-23, electric four-wheeler sales have grown by 18 times[75]. For the trucks segment, studies suggest that TCO parity will be achieved for battery-electric alternatives before 2030. Further, hydrogen fuel cells derived from renewable sources are also achieving TCO parity in certain segments by 2030, whilst the difference in TCO is only about three percent[66] for the remaining segments.

Given that technological capability exists, the policy efforts to decarbonise road transport must focus on improving manufacturing scale, developing finance avenues, and creating a conducive regulatory system that incentivises stakeholders in the EV ecosystem to participate and propagate the transition to EVs. A few policy recommendations in this regard are provided below-

- **Mainstream public transport and its electrification-** Mainstreaming public transport and its electrification involves making public transportation more accessible, efficient, and environment friendly. To mainstream public transport, it is important to ensure that it is affordable, safe, and reliable. And for electrification, focus on technologies that produce zero tailpipe emissions during operation and are powered by electricity grid that is getting greener by the day.
- **End-use-based research on battery technologies** - Research must be focused on application in the concerned vehicle segment. Best-fit battery chemistry for buses which can afford to be heavier while possessing a lower energy density might not be suitable for the two-wheeler segment. A diverse battery chemistry range for road transport can have sustainable implications from a raw material procurement perspective.
- **Rationalise subsidies provided to manufacturers** – There are certain vehicle segments which have already achieved TCO parity. Thus, the central/state subsidies and other financial incentives must be diverted towards segments that are yet to attain TCO parity. This will prompt a demand-side led transition to EVs.
- **Novel business models to finance EVs**- A key aspect in EV penetration is access to finance for procuring the EV. While subsidies support in reducing the vehicle cost, consumers must have access to formal financial avenues. Innovative business models that can ease financial access without burdening the consumer, could pave the way for increasing EVs on-road.
- **Focus on deploying EV charging station on highways**- Deploying electric vehicles (EV) charging stations on highways is a key strategy for promoting the adoption of electric vehicles as majority of the time EVs are charged at home for intra-city commuting. Highways are major transportation corridors,

---

[75] https://www.smev.in/statistics

and drivers need the confidence that they can charge their vehicles during long-distance trips. By installing charging stations along highways, EV drivers can have access to reliable charging infrastructure, enabling them to travel longer distances without fear of running out of battery charge.

- **Bring circularity in the EV value chain-** Include circularity in the design, production, use, and disposal of electric vehicles (EVs). Circularity can help to reduce the environmental impacts of EVs, can help to promote resource efficiency & security, and can create immense economic opportunities.

Concerning the hard-to-abate sectors of maritime and aviation, we observe that technological propositions are yet to attain commercial stages. In the maritime sector, Methanol as a fuel possesses a high level of technology readiness, however, it is limited by gaps in infrastructure and regulatory standards. Other RE-derived synthetic fuels will require further R&D to improve their viability. A similar scenario persists in the aviation sector where battery and hydrogen-powered aircraft are at low-technological readiness levels. Sustainable Aviation Fuels (SAF) stand out as a promising decarbonisation vector. Currently, blending of SAF with conventional fuel is permitted up to 50 percent, however, the financial implications pose a barrier towards this transition. Thus, cognisant of these gaps, policy recommendations for the hard-to abate sectors are provided below-

- **Develop sector-specific roadmaps**- Given the nascent stages of technological readiness for sustainable alternatives, a roadmap must be charted out that defines sector-wise R&D focus. This research must feed into subsequent steps which will initiate scaling of the best available technology, to keep pace with the decarbonisation efforts. The stakeholders must be identified and their roles defined, to coordinate a time-bound effort.
- **Global coordination to adopt best practices**- Knowledge transfer of technology might be critical to keep up with international standards. Thus, coordinated efforts must be initiated to enable a channel of technology transfer keeping with the best available global practices for decarbonising hard-to-abate sectors.
- **Capitalise on carbon market incentives for SAF blending:** The carbon market incentives can help airlines to capitalise on SAF blending by providing financial benefits for reducing carbon emissions. This can be achieved by focusing on interventions like carbon credits for fliers, Renewable Fuel Standard (RFS) credits, tax incentives, and more.

Further, while the Railways are set to completely electrify their broad-gauge network, hydrogen-powered trains might prove to be useful on routes where electricity network expansion is yet to be realised. Building on initiatives such as the *Hydrogen for Heritage,* hydrogen trains could be integrated for specific use-cases which can prove to be economically superior alternatives.

8 ANNEXURE

INPUT DATA FOR TWO-WHEELER SEGMENT

	Petrol	EV
Ex-showroom price (in INR)	58120	98981
RTO (in INR)	11140	0
Insurance (in INR)	10089	1152
Maintenance (in INR)	1800	3000
Mileage (kmpl)/Range (km)	50.6	109

INPUT DATA FOR THREE-WHEELER SEGMENT

	CNG	EV
Ex-showroom price	231000	292000
RTO	3613.5	0
Insurance	6022.5	5018.75
Maintenance	14654.8	7427.75
Mileage (km/kg)/Range (km)	27	55

INPUT DATA FOR FOUR-WHEELER SEGMENT

Low-cost Segment		
	Tiago Petrol ICE	Tiago EV
Ex-showroom price (in INR)	700000	1149000
RTO (in INR)	55459	0
Insurance (in INR)	13125.2	17800
Maintenance (in INR)	5663.2	3600
Mileage (in kmpl)/Range (in km)	61572.2	3732.48

Medium-cost Segment

	Nexon Petrol ICE	Nexon EV
Ex-showroom price (in INR)	1200000	1600000
RTO (in INR)	115210	0
Insurance (in INR)	24230	34579.2
Maintenance (in INR)	10454	7762
Mileage (in kmpl)/Range (in km)	95713.4	4799.2

Luxury Segment

	MG Astor Petrol	MG ZS EV
Ex-showroom price (in INR)	1500000	2690000
RTO (in INR)	115210	0
Insurance (in INR)	32295.2	60583.6
Maintenance (in INR)	8460	8962
Mileage (in kmpl)/Range (in km)	74766.2	5952.2

Taxi segment

	Tata Tigor CNG	Tata Xpress-T
Ex-showroom price (in INR)	869000	1175000
RTO (in INR)	84858	0
Insurance (in INR)	22513.6	27505
Maintenance (in INR)	49080	45339.2
Mileage (km/kg)/Range (km)	216762.8	29527.8


70
75
80
70
EESL ENERGY EFFICIENCY SERVICES LIMITED
A JV of PSUs under the Ministry of Power
EESL AND NDMC PUBLIC ELECTRIC VEHICLE CHARGING PLAZA
India's First Public EV Charging Plaza
EESL
Fast Charger (142 kW)
EXICOM
DL 10CP 3585
DL 10CP 3409
EV PARKING ONLY

VASUDHA
FOUNDATION
Green ways for a good earth!

CISRS House, 14, Jangpura B, Mathura Road, New Delhi – 110 014, India

www.vasudha-foundation.org | www.vasudhapower.in