SHAKTI SUSTAINABLE ENERGY FOUNDATION

Alliance for an Energy Efficient Economy

Green Vehicle Rating

PHASE II

A CONSUMER INFORMATION RATING TOOL

July 2021

Funded by:

Shakti Sustainable Energy Foundation seeks to facilitate India's transition to a sustainable energy future by aiding the design and implementation of policies in the following areas: clean power, energy efficiency, sustainable urban transport, climate change mitigation, and clean energy finance.

Prepared by:

Alliance for an Energy Efficient Economy (AEEE) is a policy advocacy and energy efficiency market enabler with a not-for-profit motive.

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This report is meant for educational and informational purposes only, with the intent to bring to light the environmental and legal framework around emission levels of vehicles and to educate the consumer about health and environmental impact so that they can make an informed choice while purchasing a vehicle. The ratings mentioned on the portal for vehicles are calculated based on the pollutant information provided in Form 22, other government documents, research papers, and reports. The values have been considered at face value without any cross-validation in a test laboratory.

This study has not been sponsored by any of the two-wheeler manufacturers included in the report and as such there is no conflict of interest.

AEEE has not received any compensation for rating the manufacturers in the order that they were rated in.

The ratings and methodology have been constructed by AEEE on the basis of the sources mentioned above and the report/ratings are made available on the understanding that consumers exercise reasonable due diligence with respect to its use.

The data reflected in this report/ document has been collected from the Form 22 given by the two-wheeler vehicle dealers to their buyers and the emission levels mentioned in these forms have been taken with the consent of the buyers who have been given these forms and they have been informed of the intention of such data collection.

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1. Introduction

The transportation sector has one of the highest sectoral shares of Carbon-dioxide (CO_2) emissions in India, Accounting for 13.2% emissions, the sector is the third-highest contributor of CO_2 in India (International Energy Agency, 2021). For India to meet its climate goals, there is an inevitable need to transition to clean mobility options. As with any sector, the growth of the clean mobility sector will require both supply and demand-side interventions. To avoid the causality dilemma around prioritising the focus area, a possible strategy can be to nudge customers towards greener choices. This prior conditioning of customers will keep the demand for greener variants soaring at the same time requiring manufacturers to shift to low carbon technology. In this context, the Green Vehicle Rating (GVR) is a consumer information tool that can empower all the actors in the transport ecosystem to reduce harmful emissions.

AEEE pioneered GVR, as the first time effort in India as a consumer information tool in 2019. In its previous phase, GVR identified high to low performing Internal Combustion Engine (ICE) vehicle models, in the two wheeler category. The ranking of the vehicles was based on the quantum of negative impacts of greenhouse gases and criteria pollutants. Tail pipe emissions of twenty 2-wheeler top selling models following Bharat Stage IV emissions norms were evaluated in the phase. In the second phase, GVR has evolved to include electric two-wheelers and transformed into a user-friendly web-based tool.

Damages to Health and Environment

Clean air is deemed as a human right by the World Health Organization (WHO) (DownToEarth, 2018). However, this right is being violated in most of the major Indian cities regularly. This is evident from the fact that 22 out of the 30 most polluted cities are in India as per the World Air Quality Report (IQAir, 2020). The reports state that primary sources of air pollution in the Indian context are transportation, biomass combustion for cooking, electricity generation, industry, construction, waste burning, and episodic agricultural burning. Road transport continues to heavily depend on oil and thus is a major contributor of GHG emissions and criteria pollutants in these cities. As per CSO Energy statistics (2019), oil consumption in road transport accounts for about 59.4% of total energy consumption (~ 31,060.53 KToe) in the transport sector.

Numerous negative externalities are arising out of vehicle emissions such as eutrophication, distortions in natural cycles of vegetation and wetlands, acid rains, and the adverse effect of Greenhouse Gases (GHGs) on the climate. Automobiles, through tailpipes, emit toxic compounds such as carbon monoxide (CO), oxides of nitrogen (NOx), Particulate Matter (PM), and other harmful hydrocarbons (HC). Classified as criteria pollutants, these compounds, in addition to sulphur dioxide (SO_2) are the primary cause of health impacts. The table below discusses the health impact of different vehicular pollutants:

Table 1: Health impacts of vehicular pollutants.

Vehicular Pollutant	Effect on Health
CO	• Toxic compound blocks the supply of oxygen to organs and tissues by reducing the oxygen-carrying capacity of the blood • Reduced oxygen-carrying capacity of blood leads to ailments such as weak eyesight, nervousness, and cardiovascular disorders
HC	• Compounds are carcinogenic in nature • Harmful to plant life, causing the breakdown of tissues leading to shedding of leaves, flowers, and twigs
NOx	• Compound is a lung irritant leading to respiratory infections primarily affecting children • Retards the rate of photosynthesis in the plants
SO_2	• Poisonous compound that affects plant and animal life alike • Even a low concentration of this compound is sufficient to cause respiratory diseases such as asthma, emphysema, and bronchitis in humans
PM	• Small particulate matter enters the lung and bloodstream, causing respiratory and cardiac problems • Minimal exposure can have adverse effects that can be seen in the form of aggravated respiratory symptoms such as difficulty in breathing and irritation in the airway

Source: Adeyanju Anthony A. 2018

Quantifying Losses

Burning fossil fuels has resulted in damages estimated at around USD 2.9 trillion, equivalent to 3.3% of the world's GDP (McCarthy, 2020). Post-2016, the global economic losses due to natural calamities are estimated above USD 200 billion per year. The economic cost of climate change-related damages is estimated to be approximately USD 225 billion in 2018. In the same year, an estimated 4.5 million deaths were attributed to fossil fuel-driven pollution exposure (Arora, 2019). Table 2 represents the damages in monetary terms due to air pollution estimated as of 2018.

Table 2: Economic costs incurred due to air pollution

Damage Incurred	Economic cost (in billion USD)
Disability caused due to chronic illness	200
Asthma	17
Premature births	90
Forced sick leaves	100
Child deaths	50
Adult deaths	2400

Source: Centre for Research on Energy and Clean Air 2020

In terms of losses to agricultural productivity, the World Food Programme report of 2018 indicates grim predictions for the agriculture sector if the trend of repeated climate change impacts continue. A decline in the production of major cereal crops such as maize, wheat, and rice by 45%, 50%, and 30% respectively is estimated if current trends continue till 2100. Climate change induced rise in temperature will further increase the occurrences of droughts and cause unpredictable rainfall patterns (World Bank, 2013). As a result, the crop yield per hectare will become incompatible with the needs of the rising population.

Emphasis on two and three-wheelers

The 2011 census estimated that 31.2 % of India's population lives in urban areas. By 2030, the forecast is that 40% of our population will settle in urban areas (Ministry of Finance, 2018). Public transport facilities have failed to match the needs of the growing population, forcing most Indian commuters to depend on two and three-wheelers. In 2019-20, India was home to the largest 2-wheeler market globally, with a domestic share of 80.83% of all motor vehicles present (Society of Indian Automobile Manufacturers, 2021). The past decade has seen 2-wheeler vehicle sales almost double; from 11.77 million units sold in 2011, to 21.18 million units sold as of 2019 (Singh, 2016).

In 2018, the International Road Federation undertook a study in several countries to identify category-wise vehicle penetration per 1000 people. According to the estimates, India topped the list among 192 countries in terms of the number of 2-wheeler and 3-wheeler motor vehicles plying on the roads. The growing share of private ownership is also reflected in the fact that the number of two-wheelers sold between 2011 to 2016 (53.6 million units) is almost equal to the total number of registered vehicles that existed in India in 2001 (55 million units) (Singh, 2016).

In the future, the effects of the pandemic on transportation choices also voice the reason for an emphasis on two and three-wheelers. Rising health concerns among the public have led to a general shift towards private modes of transport over public transportation. Globally, the change in preference of choice of transportation has been observed to be long-term in nature. In recent surveys on modal share comparison between pre and post COVID scenarios, a decrease in public transport usage was observed in the metro cities (Thakur, 2020). As the economy recovers, and the spending capability of the consumer improves, private vehicle ownership is bound to increase. In the Indian context, the 2 - wheelers demand focus owing to their larger presence, and economic viability amongst a larger audience.

Do EVs pollute?

Although petrol and diesel-run vehicles constitute the bulk of the on-road fleet in India, electric technology is gradually gaining momentum in the auto sector. Also, there is growing support from policymakers towards e-mobility. With the penetration of electric variants of two-wheelers and three-wheelers, the question arises "Are e-mobility solutions cleaner than their counterparts?" Unlike Internal Combustion Engine (ICE) vehicles, Electric Vehicles (EVs) have zero tailpipe emissions. At a localized level, it does translate to cleaner air. However, the EVs may still result in GHG and criteria pollutant emissions as they draw energy from fossil fuel-powered electric sources. In India, as of 2021, 61.5% of the total power generation mix is still dominated by thermal sources (Ministry of Power, 2021).

Typically, thermal power stations use fossil fuels such as coal, lignite, gas, and diesel. The power generation process generates significant emissions such as PM, SO_2, NO_x, CO, CO_2 and, volatile organic compounds (VOC). Therefore, there are health and environmental impacts due to the emissions generated by the thermal-power plants powering the EVs. **However, in the future, as the total power generation mix shifts towards cleaner technology the benefits from EVs will increase manifold.**

Nudging ICE to be Efficient

India's two and three-wheeler segments represent almost 85% of the total on-road vehicles (NITI Aayog, 2018). ICE two-wheelers saw annual sales upwards of 21.2 million units in 2018-19, and this figure is poised to grow (Society of Indian Automobile Manufacturers, 2021). A shift to EVs as the primary on-road vehicles is not imminent. Multiple factors, such as the provision of adequate charging infrastructure, economically viable battery technologies, and consumer affordability, are prerequisites that need to be fulfilled for such a transition. Therefore, in the larger context of achieving reduced pollution levels, consumers must be nudged towards purchasing cleaner and efficient vehicles. Hence, it is deemed important to rate and compare the EV models alongside ICE models under the GVR program,

For the analysis, GVR considers a composite approach to account for emissions both from fuel sources (petroleum refineries in case of ICE and thermal power plant for EVs) and tailpipe emissions. GVR adopts the Plant-to-Wheel (PTW) emissions approach. This approach considers upstream (limited to fuel production and distribution) and tailpipe emissions (GHGs and air pollutants) due to the combustion of fossil fuels.

Shift from Emission Intensive Mobility to Zero-Emission Mobility

There is no silver bullet to solve the issues of air pollution. A combination of a well-researched, technically proven and rapidly implementable set of interventions will be required to mitigate climate change before we enter the irreversible phase. One of the most effective ways to nudge the transport sector towards an efficient and cleaner future is to influence consumer purchases favoring more fuel-efficient and less polluting vehicle models. Bringing a change in consumer choices starts with reliable and straightforward information - on impacts of pollutants and CO_2 emissions - as they purchase vehicles. Well-informed consumers may appreciate the information and adopt cleaner variants, resulting in increased demand and encouraging automakers to alter technologies. It may also boost the implementation and effectiveness of government efforts on saving fuel use and avoiding emissions from vehicles. In an attempt to deter grave repercussions on health and the environment, GVR provides a monetized metric to nudge consumers towards cleaner and more sustainable choices.

The SDG Connect

Economic activities have an impact on the environment. The production of goods and services requires energy and raw materials. Minerals, water, food, and metals are obtained from the environment. The processes of extracting, using, and transporting these resources have varied impacts on the environment. In the disparities between developed and developing economies, the latter necessarily needs to undertake activities to match their socio-economic development goals. Thus, sustainability and thereby sustainable development is pertinent to balancing the effect of undertaking the economic activity and the corresponding environmental degradation it causes (Jackson, 2016).

The transportation industry, among others, is hugely responsible for environmental damages, and hence sustainable development cannot be met without a pursuit for more sustainable modes of transportation. The GVR tool aims to act as a policy enabler by bridging information gaps for cleaner consumer choice, shifting manufacturers' priorities towards increasing environmental performance, and helping governments achieve the UN-directed Sustainable Development Goals (SDGs).

Specifically, **GVR will be an enabler for SDG7, SDG 12, and SDG 13**. SDG7 aims to ensure access to affordable, sustainable, and modern energy for all. GVR will harbor inquisition amongst the consumers to choose greener variants which will have a ripple effect on the demand for clean energy, thus emboldening SDG 7. SDG 12 focuses on ensuring sustainable consumption and production patterns. The transition towards a greener variant through demand-pull will nudge policymakers and auto-manufacturers to champion sustainability. Finally, for SDG-13, the aspects of climate finance and global commitment to reverse the climate crisis are key. Climate finance continues to be surpassed by fossil fuel investments (United Nations Department of Economic and Social Affairs 2016). By influencing the demand side to opt for cleaner alternatives, GVR nudges the industry to prioritize environmental performance. This will prompt an increase in sustainable product investments and push the economy to align with global mandates for climate change mitigation. The combined pursuits supporting SDG12 and SDG13 will result in overarching benefits to meeting SDG7 goals. There is no greening the transport sector without greening the grid (Kwatra, 2021).

2. Objective and Scope of Green Vehicle Rating

Development of GVR – Steppingstone for a Drive towards Clean Transport

As a first-time effort in India, AEEE has pioneered the Green Vehicle Rating (GVR), the country's only vehicle rating system based on environmental performance. It serves as a consumer information tool that identifies high to low-performing vehicle models, in two and three-wheeler categories, in terms of the negative impacts of GHG emissions and criteria pollutants. Along with a comparative analysis of vehicle models, the GVR shows the external costs of pollution - both GHGs and criteria pollutants.

Figure 1: Objectives of GVR

By making this information available to consumers, the goal is to reshape their knowledge on the real cost of owning a vehicle, beyond retail price tags and self-reported mileage data supplied by auto dealers, which are commonly used as criteria during vehicle purchase in India. The purpose of the initiative is to sensitize consumers about the environmental impact of vehicle use, a dedicated web portal has been created which would allow consumers and other stakeholders to check the GVR of a vehicle model (currently covering 2 and 3 wheelers) and also peruse the methodology, data, and assumptions used to rate the vehicles.

GVR broadly serves three functions:

- To enable buyers to find vehicle model ratings based on their environmental performance
- To inform/ educate the buyers about the health and environmental costs of vehicular emissions
- To inform the buyers about the real cost of owning the vehicle

About GVR Phase I

The first phase of GVR was carried out in 2018 and it evaluated the tailpipe emissions of twenty 2-wheeler models and two 3-wheeler models. These vehicles were ranked based on their environmental performance. It was observed that the costs of emission controlling technologies in vehicles are not being internalized in the retail price of the vehicle, which is a dominant factor in costs of ownership. Further, the monetary losses from environmental externalities due to emissions are pivoted to topographic and demographic factors of the region of vehicle use. Distilling these factors into a concrete monetary value is a constructive way forward to allow consumers to add to their purchase decisions and progress from being aware to acting. Thus, it was established that the real cost of ownership of a vehicle is a consequence of a medley of factors such as fuel efficiency, kerb weight, retail prices, use of vehicular technologies such as engine and emissions control devices, and contextual (non-vehicle technology) factors such as fuel quality, and driving conditions that together determine the exhaust emissions released.

Scope of GVR Phase II

Expanding the scope of GVR to include electric variants of two-wheeler and three-wheeler segments and incorporate more ICE-models

Although petrol and diesel-run vehicles constitute the bulk of the on-road fleet in India, electric technology is gradually gaining momentum in the auto sector. Also, there is growing support from policymakers towards e-mobility. As discussed in the previous chapter, EVs have zero tailpipe emissions but they may result in GHG and criteria pollutant emissions as they draw energy from fossil fuel-powered electric sources. In other words, the emissions shift from tailpipe to power plants in the case of EVs.

Therefore, it is deemed important to rate and compare the EV models alongside ICE models under the GVR program. In the case of an EV, there is no combustion of fuel in the vehicle tank; rather the emissions occur at the power generation plant i.e. the power plants can be regarded as the counterparts of vehicle tanks of ICE models.

The first phase of GVR covered only BS-IV compliant ICE vehicles. The approach adopted to estimate the ratings was tank-to-wheel emissions. However, in the second phase, the focus is on BS-VI compliant ICE models and electric variants of both two-wheelers and three-wheelers. Therefore, to rate EV models alongside ICE models, we calculate the upstream and tailpipe emissions and follow plant-to-wheel emissions. A detailed description of the approach is provided in chapter 4.

Benefits of GVR

GVR provides a slew of benefits for all the stakeholders in the value chain as seen in Figure 2. To make informed decisions, the consumers need a basic understanding of the causes, likelihood, and severity of the impacts of their inefficient choices and the range, cost, and efficacy of different options to limit or adapt to them. GVR offers information that is easy to understand and expands the common notion of the cost of owning a vehicle by incorporating health and environmental damage costs into the picture. It allows them to compare vehicles based on their environmental performance and make prudent purchase decisions.

For the Government, it allows meeting national climate and sustainable development goals. At the same time, it will greatly curtail the runaway costs of climate change, especially over a long term period. Moreover, the clean energy economy is poised to be the growth industry for the future worldwide, and the nation could be at the vanguard of that trend if clean technology like Electric Vehicles (EVs) is adopted. Finally, reducing emissions with a shift towards cleaner forms of transportation will not only help slow global warming but will also improve air quality, reducing the public health burden on the nation.

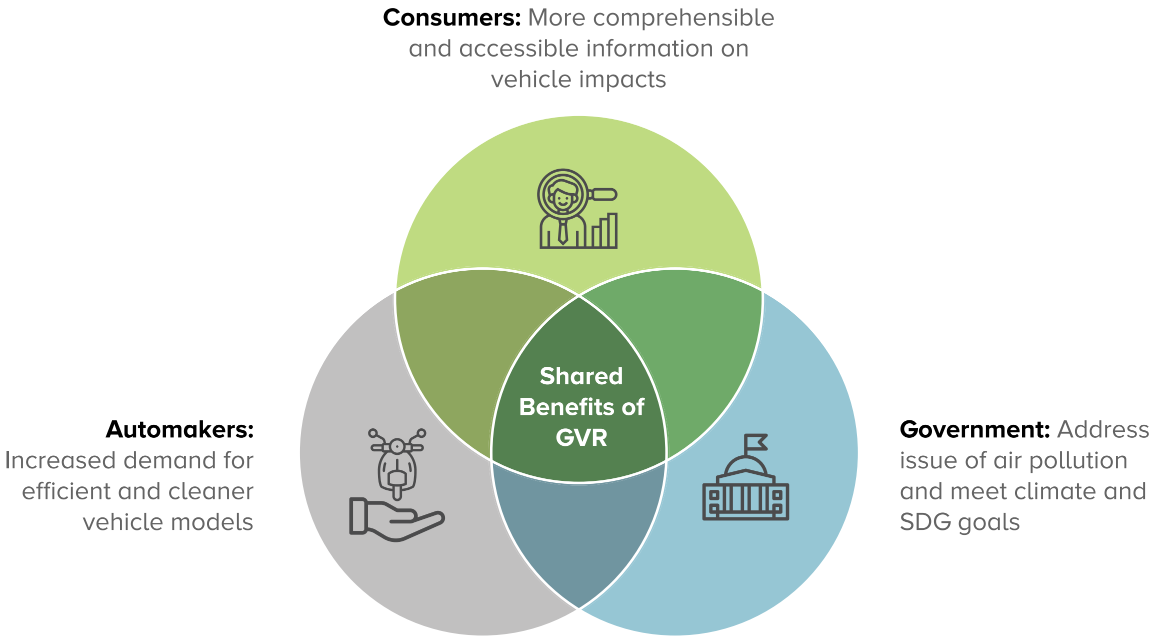


Figure 2: Shared Benefits of GVR

Even automakers will reap sundry benefits from GVR. It puts the spotlight on high-performing vehicles for consumer knowledge thereby increasing their demand. This in turn addresses the Catch-22 situation for automakers by allowing them to scale up the manufacturing of greener variants and enjoy the benefits of economies of scale. Concurrently, GVR ensures a coordinated policy action that provides guidance, accountability, and clarity on the future of clean vehicles in India.

3. Literature Review

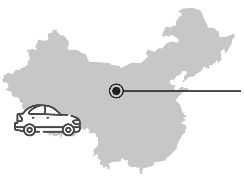
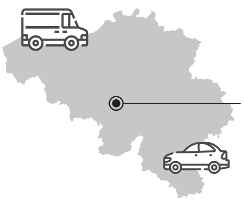
International Experience

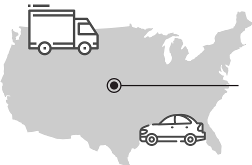
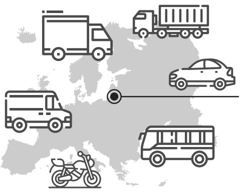
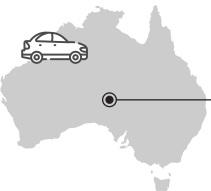
Vehicle rating programs operating in different regions of the world have set a positive precedent in creating awareness on various environmental parameters and enabling consumers to make greener vehicle purchases. The outcome of the literature survey suggests that mandatory environmental information disclosure leads to an incremental difference in the consumer's assessment of products, willingness to pay, and final consumption. Additionally, an increase in demand for better products depends on the context in which consumers make the decision, how they process the information and how the information is presented to the target groups (*Shimshack, 2013*).

Table 3 is an attempt to understand and compare the existing vehicle rating programs based on their origin and management (government/private/joint), regional scope (country/ continent), the format of communicating the results to users, types of vehicles considered (light duty/ heavy duty; new/ second hand), and types of fuels considered (Petrol/ diesel/ LPG/ CNG/ electric). More details can be found in annexure 1.

Table 3: Summary of general features of International Vehicle Rating Programs

International Vehicle Ratings: General Features

Name of the Rating Program and Country		Developing Agency	Format of Dissemination	Approach (Well to Wheel/ Tank to Wheel)	Fuel Types	Vehicle Types
	Green Car (China)	Innovation Centre for Energy and Transportation with support from the Energy Foundation, China.	Online assessment and comparison tool: www.greencarchina.org	Well to Wheel (Tailpipe, upstream vehicle emissions)	Petrol, Diesel, CNG, LNG, LPG, Conventional Hybrid, PHEV	Cars
	EcoScore (Belgium)	VITO, VUB and ULB (Research Institutes and Universities) on behalf of the Flemish government	Web based calculator and downloadable data: http://ecoscore.be/en/calculator#	Well to Tank, Tank to Wheel	Petrol, diesel, CNG, LPG, Bio diesel	Light Duty Vehicles- Cars

Name of the Rating Program and Country		Developing Agency	Format of Dissemination	Approach (Well to Wheel/ Tank to Wheel)	Fuel Types	Vehicle Types
	**Next Green Car (UK)**	Auto consultants	Web based calculator: http://www.nextgreencar.com	Well to Wheel (tail pipe, fuel production and vehicle production emissions)	Petrol, diesel, PHEV, EV, Hydrogen, Hybrid	Cars
	**Greener Cars (US)**	ACEEE	Web based calculator: https://greenercars.org/greenercarsratings	Well to Wheel (tail pipe, upstream) + Embodied Emissions	Gasoline, diesel, PHEV, EV, CNG, Fuel cell	Cars and light trucks
	**Clean Vehicle Europe (CVE) (Europe)**	EU Commission: under European directive 2009/33/EC; Law to account for energy and carbon impacts from road vehicle purchases	Clean Vehicle Portal (CVP): http://www.cleanvehicle.eu	Tank to Wheel (Tail pipe emissions)	Petrol, diesel, PHEV, BEV	All kinds of road transportation
	**Green Vehicle Guide (GVG) (Australia)**	Department of Infrastructure and Regional Development	Web based calculator: https://www.greenvehicleguide.gov.au/#	Tank to Wheel	Petrol, diesel, LPG, Electric and Plug In Hybrid	Cars
	**Rightcar NZ (New Zealand)**	NZ Transport Agency	Website: http://rightcar.govt.nz/co2-ratings.html	Tank to Wheel	Petrol, diesel, LPG, Electric and Hybrid	Only lists cars, 4WDs, SUVs, vans and utility vehicles that have been sold in NZ since 2005

India Experience

Absence of environmental performance rating

In India, vehicle rating systems have been synonymous with crash safety performance tests. A mandatory assessment program called the Bharat New Vehicle Safety Assessment Program (BNVSAP) intends to gauge car safety performance based on crash tests conducted by the Ministry of Heavy Industries (Mishra M., 2020). In the context of securing human life, the aspects of human health and environmental damages are yet to gain policy traction in India.

Better environmental performance refers to the reduced level of emissions from vehicles. These emissions have been known contributors to public health degradation and climate change. The corresponding economic damages are significant. The catch however is that the impact isn't immediately observable. In today's world where climate change mitigation is urgent, the transportation sector must undertake efforts to reduce vehicular emission impact.

Discussing India specific regulations

Adoption of BS-VI norms

As per the new emission standard, automobile manufacturers, as well as oil companies in India, have made changes to comply with BS-VI norms. For optimal results in reduced vehicular emissions, a BS-VI engine must necessarily run on BS-VI grade fuel. Given that BS-VI has been in effect only since April 2020, it implies that there are close to 200 million vehicles that are compliant only with the previous standards. While the ill effects of running existing vehicles on BS-VI grade fuel are minimal, the expected reduction in pollutant levels will not be met. (Mishra R., 2020)

The major difference in the new BS-VI emission norms is that they cause five times lesser sulphur content emission in comparison with BS-IV. The nitrogen oxides produced as a result of BS-VI combustion are 70 and 25 percent less for diesel and petrol engines respectively. The BS-VI vehicles also come with certain auxiliary technologies. For example, all diesel motors are to include a Diesel Particulate Filter (DPF) and Selective Catalytic Reduction (SCR) technologies.

Upgrade to BS-VI: Changes to emission levels

The two-wheeler vehicle segment in India is categorized into subclasses based on the engine size and top speed of the vehicle (Refer Table 4). The top speed of the vehicle is indicative of the engine performance and has a direct correlation with higher emission levels. Taking cognizance of the wide-ranging two-wheeler models available in India, the norms vary corresponding to the class of two-wheeler.

Table 4: Classification of Two-wheeler in India

Class of two-wheeler	Description	
	Engine Size (in cc)	Top Speed (in kmph)
Class 1	Less than 150	Between 50 to 100
Sub class 2.1	Any engine capacity	Maximum speed less than 115
Sub class 2.2	Any engine capacity	Equal to or more than 115 but less than 130
Sub class 3.1	Any engine capacity	Equal to or more than 130 but less than 140
Sub class 3.2	Any engine capacity	Maximum speed equal to or more than 140

Source: (ECMA, n.d.)

As mentioned in the previous section, the acceptable pollutant emission values were significantly brought down in the shift to BS-VI norms. The BS-VI norms have reduced the permissible PM emission limit by 89% (ICCT, 2016). The other major pollutants have also had significant reductions as seen in Table 6.

Table 5: Change in permissible emission value of major pollutants

Class of 2-wheeler (Refer Table 4)	Percentage change in permissible pollutant value (BS IV to BS VI)		
	CO	NOx	HC
1, 2.1	-29%	-85%	0%
2.2	-49%	-82%	0%
3.1,3.2	-49%	-70%	0%

Source: (ICCT, 2016)

Emission and Fuel economy standards: State directed norms

The rhetoric surrounding GVR has been encapsulated by the phrase – 'Kitna Leti Hai' which is indicative of the hidden environmental and health costs arising due to fossil fuel consumption of the vehicle. The rising demand for private vehicles has seen a corresponding rise in fuel demand. Reducing fuel consumption by way of increasing the fuel efficiency of vehicles is a way to moderate vehicular emissions.

The Bureau of Energy Efficiency (BEE) functioning under the Ministry of Power (MoP), is the nodal department, in charge of setting up vehicular fuel-efficiency norms. Termed as the Corporate Average Fuel Economy (CAFE) norms, it relates the Corporate Average Fuel Consumption (in litres/100km) to the Corporate Average Curb Weight. This applies to all the passenger cars sold in a fiscal year by the manufacturers. The BEE also develops fuel economy norms for Heavy-duty, light, and commercial vehicles (Bureau of Energy Efficiency, 2020).

India had set fleet average targets to reduce CO_2 emissions. 2015, as a baseline year, had a fleet average CO_2 emissions value of 138 g/km approximately. The BEE had set a target for 2022, to reduce the CO_2 emissions to 113 g/km. Corresponding fuel consumption standards were notified by the BEE, which is expected to bring about energy savings to the tune of 22.97 million tons of oil equivalent by the year 2025.

Table 6: Notified fuel economy standards in India

Compliance year as specified in the notification	Corporate Fuel Consumption Standard		
	Average Fuel Consumption (in litres/100km)	Permissible CO_2 Emission (in gm of CO_2/km)	Vehicle Average Weight (in kg)
2017-18	5.5l/100km	129.8	1037
2022-23	4.78l/100km	113	1145

Source: (Wadhwa)

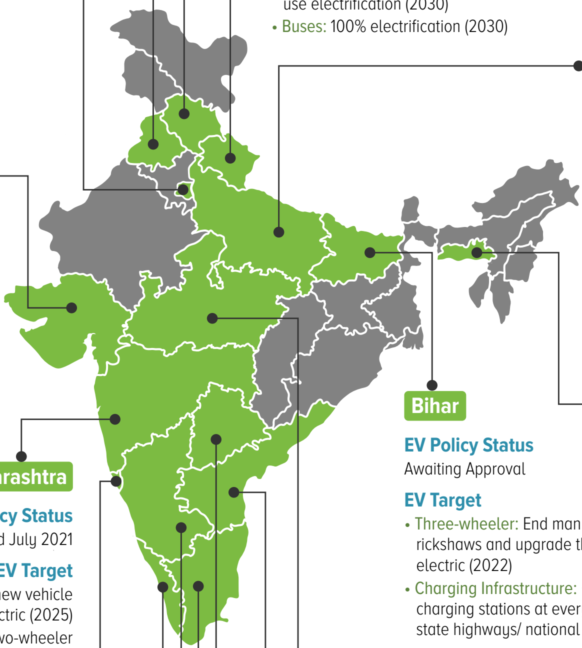
Enabling EVs in India

A sound EV policy identifies the local development objectives, development opportunities and accounts for the barriers present to achieve the same. The two-wheeler segment in India occupies the largest share of on-road vehicles. But the electric two-wheeler market share was estimated to be around 1.2% in the fiscal year 2019-20. Electric three-wheelers in India are primarily used for commercial purposes. The three-wheelers are critical for short-haul delivery and last-mile connectivity applications in congested areas. Tier-1 and

Tier-2 cities have an estimated 1.5 million e-rickshaws plying on Indian roads (Aparna, Zifei, & Anup, 2019).

In keeping with the large share of 2 and 3-wheelers, the state-specific EV policies must expand the scope to incorporate relevant vehicle segments. Table 7 gives a brief snapshot of various EV policies being implemented in the Indian States. Most of the states are instituting a state EV funding for the provisions mentioned in the policy. This fund will be vitalized through 'feebate concept' i.e. by adopting measures by which inefficient polluting vehicles will incur a surcharge (fee) while the efficient ones receive a rebate (bate).

Table 7: Snapshot of State-EV policies in India



Himachal Pradesh

EV Policy Status
Approved July 2021

EV Target
- All Vehicle Segments: Battery Electric Vehicles (BEVs) form at least 15% of the new vehicle registration by 2025

Punjab

EV Policy Status
Awaiting Approval

EV Target
- All Vehicle Segments: 25% of total vehicle registrations to be EVs (2024)

Uttarakhand

EV Policy Status
Approved October 2018

EV Target
- All Vehicle Segments: 100% public transport (2030)
- Two-wheeler: 100% commercial use electrification (2030)
- Three-wheeler: 100% commercial and freight electrification (2030)
- Four-wheeler: 100% commercial use electrification (2030)
- Buses: 100% electrification (2030)

New Delhi

EV Policy Status
Approved August 2020

EV Target
- All Vehicle Segments: 25% of total vehicle registrations to be EVs (2024)
- Buses: 1,000 e-buses (2020)

Uttar Pradesh

EV Policy Status
Approved August 2019

EV Target
- All Vehicle Segments: 10 Lakh EVs (2024)
- Two-wheeler: 50% commercial use electrification (2030)
- Three-wheeler: 50% commercial use electrification (2030)
- Four-wheeler: 50% commercial use electrification (2030)
- Buses: 1,000 e-buses (2030)

Gujarat

EV Policy Status
Approved June 2021

EV Target
- e-2-Wheelers: 1,10,000
- e-3-Wheelers: 70,000
- e-4-Wheelers (Private and Commercial): 20,000
- Total EV: 200,000 (2025)

Bihar

EV Policy Status
Awaiting Approval

EV Target
- Three-wheeler: End manual paddling rickshaws and upgrade them to 100% electric (2022)
- Charging Infrastructure: Create fast charging stations at every 50 km on state highways/ national highways (2022)

Meghalaya

EV Policy Status
Approved 2021

EV Target
- All Vehicle Segments: 15% of EVs in 5 years

Maharashtra

EV Policy Status
Revised July 2021

EV Target
- All Vehicle Segments: 10% of new vehicle registrations to be electric (2025)
- 2-Wheelers: 10% of new two-wheeler registrations to be electric (2025)
- 3-wheeler: 20% of new three-wheeler registrations to be electric (2025)
- 4-Wheeler: 5% of new four-wheeler registrations to be electric (2025)
- Buses: 15% of MSRTC's existing bus fleet to electric (2025)

Madhya Pradesh

EV Policy Status
Approved October 2019

EV Target
- All Vehicle Segments: 25% of total vehicle registrations to be EVs (2026)

Andhra Pradesh

EV Policy Status
Approved June 2018

EV Target
- All Vehicle Segments: 10 Lakh EVs (2024)
- Buses: Full electrification (2030)
- Charging Infrastructure: 1 Lakh stations (2024)

Goa

EV Policy Status
Awaiting Approval

EV Target
- All Vehicle Segments: 30% of annual vehicles registered to be electric from 2025
- Buses: 500 e-buses by 2025

Telangana

EV Policy Status
Approved August 2020

EV Target
- All Vehicle Segments: 15% electrification (2025)
- Two-wheeler: 80% electrification (2025)
- Three-wheeler: 80% electrification (2025)
- Four-wheeler: 70% commercial + 30% private cars (2025)
- Buses: 40% electrification (2025)

Tamilnadu

EV Policy Status
Approved September 2019

EV Target
- Buses: 5% total bus fleet (2030)

Kerala

EV Policy Status
Approved March 2019

EV Target
- All Vehicle Segments: 10 Lakh EVs (2022)
- Buses: 6,000 e-buses (2025)

Karnataka

EV Policy Status
Approved September 2017

EV Target
- Three-wheeler: 100% electrification in Bengaluru city (2030)
- Four-wheeler: 100% electrification of cab aggregators in Bengaluru city (2030)

Source: Authors' Analysis

4. Methodology

This chapter covers the approach, assumptions, and analysis process used to calculate the rating for phase two of the GVR launched in 2021 to provide model-specific information for both ICE and EV. GVR ratings of the models can be accessed online at https://green-vehicle-rating.aeee.in/.

Approach to calculate GVR

Vehicles generate negative externalities from the stage of production till the disposal of the vehicle. There are two types of costs used to estimate the environmental externalities – control costs and damage costs. The control cost represents the cost incurred to reduce pollution, whereas damage cost focuses on repercussions due to pollution (Vaidyanathan, Slowik, & Junga, 2016). The GVR uses a 'damage cost' methodology to estimate the costs of negative environmental and health-related impacts of criteria pollutants and GHGs. These costs are expressed in Indian rupees (INR, or ₹) per kilometer (km). This methodology is based on principles of environmental economics and is preferred over a 'control cost' approach, to avoid incorrect valuation (Vaidyanathan, Slowik, & Junga, 2016).

Every unit distance a vehicle move entails fuel combustion and the release of a unit mass of pollutants and GHGs from the vehicle's tailpipe, which negatively contributes to the environment and human health. The negative impacts from each unit mass of pollutants and GHGs released carry a monetary cost. This cost varies by pollutant type, source (transport sector – cars/bikes, trucks), and geographical and demographic features of the city/country (e.g. the population density, average life expectancy, ambient conditions, and regional topography, to name a few). These are known as social costs, measured in INR/gram (g). In other words, the social costs for each pollutant and GHG represent the money required to undo the damages caused by every gram of pollutant released.

When looking at EVs, power plant emissions account for approximately 80% of the emissions in the EV lifecycle, as shown in Figure 3. It will be unfair to compare 0% tailpipe emissions from EVs with 45% tailpipe emissions from ICE vehicles. Therefore, to rate and compare EV models alongside ICE models under the GVR programme, we have expanded the approach from "Tank-to-Wheel" to "Plant-to-Wheel" emissions.

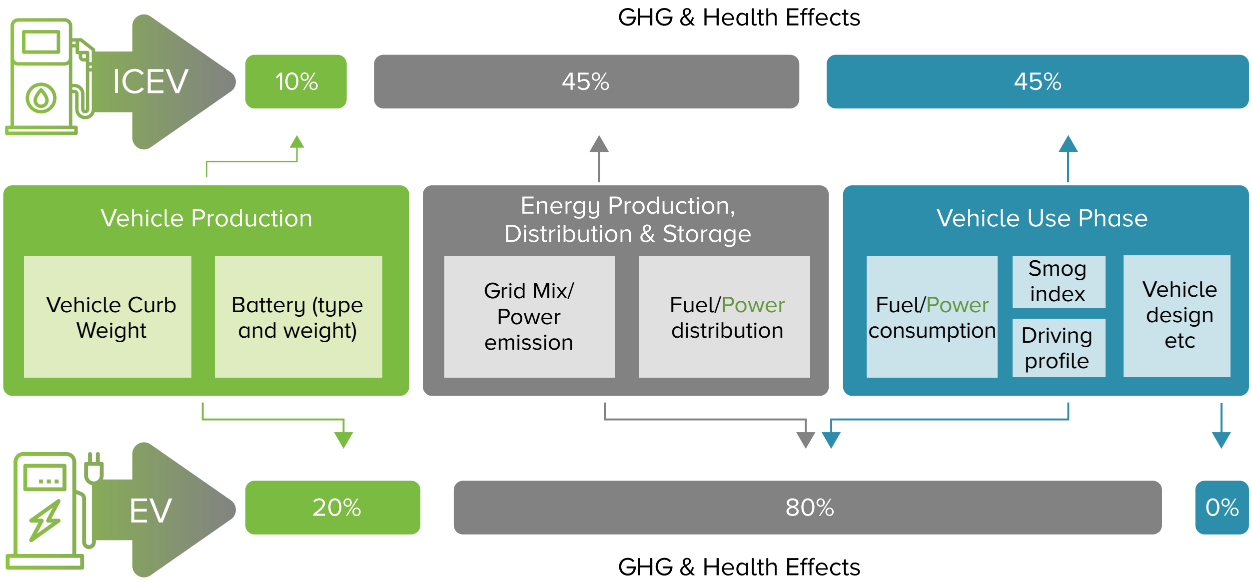


Figure 3: Environmental and health effects of ICE and EVs

Source: (Innovation Center for Energy and Transportation, 2015)

As illustrated in Figure 3, zero percent emission by EV in the vehicle use phase (tailpipe emissions) does not translate to EVs having zero harmful effects on our health and the environment. Vehicle ownership for both ICE and electric vehicles is characterized by three blocks – 1) Vehicle production, 2) Energy production, distribution and storage and 3) Vehicle use phase. The quantum of GHG and health impacts caused by each block for the two categories of vehicles are as shown. 80% of EV pollution impact is caused by the electricity grid. A greener grid can significantly improve the environmental performance of electric vehicles.

Key steps:

To calculate the different vehicle models' GVR ratings, the study has adopted a five-step approach, as shown in Figure 4. The key steps include data collection, classification of emissions impact, monetisation, normalisation, and cost and rating calculation. Each of these steps is discussed in detail below:

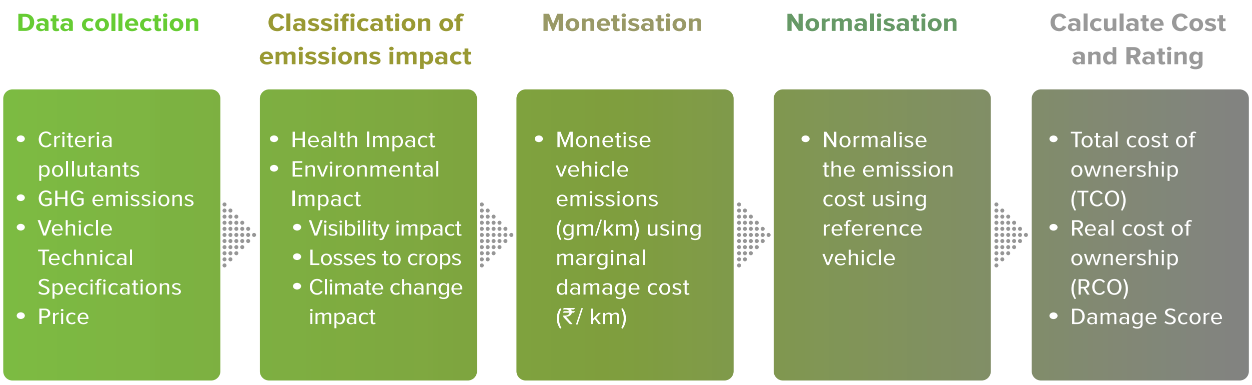


Figure 4: Key steps to calculate Green Vehicle Rating

Step 1: Data Collection

The first and most crucial step in the rating process is data collection. There are two types of data being collected – emissions data (on both upstream and tailpipe emissions) and data on vehicle specifications (technical and financial).

Data Sources for ICE vehicles

Information on criteria pollutants primarily CO, NOx, HC, and PM emitted from tailpipe sourced directly from Form 22. It is issued by the auto manufacturers to comply with the Motor Vehicles Act of 1988, Rule 47(g), 115, 124(2), 126A, and 127(1) and 127(2) (Center Motor Vehicle Rules, 1989). As part of a first-time government initiative on vehicle emissions data disclosure in India, since April 2017, vehicle manufacturers are required by the national Ministry of Road Transport and Highways (MoRTH) to declare the pollutant levels of each vehicle model that they produce on the Road Worthiness Certificate, also known as 'Form 22'. For vehicles running on petrol/compressed natural gas (CNG)/liquefied petroleum gas (LPG), EVs, and hybrid vehicles, the pollutants included in Form 22 are CO, HC, Non-Methane HC, NOx, and HC+NOx. Automakers are only required to declare PM levels in the case of diesel vehicles. Type approval tests are conducted to measure the pollutant levels at government-authorized testing agencies across India. Once the pollutant levels are determined, vehicle manufacturers sign Form 22 and hand two copies per vehicle model to the automotive dealers - one for vehicle registration at the Regional Transport Office (RTO) and another one as a consumer copy.

Similar to Phase I, we followed a multi-tier approach to collect Form 22. At first, we reached out to automotive dealers directly to furnish Form 22. However, the dealers were either reluctant to disclose this information or unwilling to share it until we make a purchase. Some of them also highlighted the fact that post-BS-VI, they are no longer receiving Form 22. One dealer in Delhi and a few in Kerala, Pune, and Bangalore shared Form 22 with us. We also contacted automotive manufacturing companies directly via their corporate email addresses and press inquiry forms available on their websites. However, similar to Phase I, the response was minimal. Therefore, AEEE made use of the personal and professional networks of its own personnel to source Form 22. We collected 29 Form 22 for two-wheelers, with no success for three-wheelers.

Sulphur oxide (SOx) emissions are estimated based on the sulphur content of the BS-VI fuel using the vehicle model's fuel economy (TransportPolicy.net, n.d.). Tailpipe GHG emissions primarily include CO_2, methane (CH_4), and nitrous oxide (N_2O). Carbon emission factors are estimated using the formula specified in Table 9. Methane is assumed to be 20% of HC, and N_2O emissions are estimated as 0.008 g/km for diesel vehicles (Next Green Car, 2016). Fuel economy estimates for two-wheelers and four-wheelers are published by the Society of Indian Automobile Manufacturers (SIAM). However, they have not updated the fuel economy for BS-VI models for two-wheelers. Therefore, we have sourced the fuel economy for these models from a third-party dealer website (bikewale, n.d.). Other technical and financial specifications such as engine size, price, depreciation cost, tyre replacement cost, etc. have also been sourced from the manufacturer and third-party dealer websites. Fuel costs, such as petrol and diesel prices, are sourced from the Ministry of Petroleum and Natural Gas (MoPNG). The fuel prices are increased at the rate of 3% year on year based on the estimate used by the Rocky Mountain Institute (RMI) (Patil & Ghate, July 2020).

For upstream emissions, we considered both secondary literature and government sources. However, the data on upstream emissions for India remains limited. Therefore, we have used the upstream information on criteria pollutants and GHG emissions from the American Council for an Energy-Efficient Economy's (ACEEE) GreenerCars initiative (Vaidyanathan, Slowik, & Junga, 2016). The same emissions data have been utilised by China in their green car methodology. In the future, there is a need to find India-specific data on upstream emissions. Detailed information on the data type, parameters, and sources for ICE vehicles is summarised in Table 8.

Table 8: ICE vehicle data type, parameters and sources

Data Type	Parameters	Source
Tailpipe Emission Data	Criteria Pollutants (CO, NOx, HC, PM)	Form 22
	Carbon Emissions (gm/km)	Method II: IPCC, MoPNG
	Methane (CH_4), N_2O, and SO_2	(Next Green Car, 2016); (TransportPolicy.net, n.d.)
	Global Warming Potential	(IPCC, 2018)
Upstream Emission Data	Criteria Pollutants and GHG Emissions	(Vaidyanathan, Slowik, & Junga, 2016)
Vehicle Specifications (Technical and Financial)	Price	Manufacturer websites
	Fuel Efficiency (km/litre)	Third-party dealer websites
	Costs (such as Depreciation, Finance, Tyre replacement, Insurance, etc.)	Third-party dealer websites (such as droom)

Table 9: CO_2 Emission Factors for BS-VI compliant petrol and diesel vehicles

Fuel Type	Default Carbon Content (kg/GJ)	Oxidisation Factor	Net Calorific Value (TJ/Gg)*	Carbon Molecule Mass Ratio	Fuel Density (Kg/litre)**	Carbon Dioxide emission Factor (g/litre)
Petrol	18.9	1	44.3	3.67	0.748	2296.35
Diesel	20.2	1	43	3.67	0.828	2637.07

Source: *Default values set by IPCC
** As per BS IV fuel specifications

Data Sources for EVs

In the case of EVs, there are no tailpipe emissions. Data is collected primarily on upstream emissions and vehicles' technical and financial specifications. The impact of geographic and temporal differences in the electricity generation mix has not been considered. We have used national average grid emissions rates for carbon emissions. Both the present and forecasted estimates of grid emissions, along with transmission and distribution (T&D) losses, are sourced from the Central Electricity Authority (CEA, 2020). The grid emission factors considered account for the share of renewable energy in power generation. Criteria pollutant emission factors are sourced from the 2008 study done by Guttikunda & Jawahar on thermal plant emissions (Guttikunda & Jawahar, 2018). For EVs, the fuel economy is calculated based on the range and battery capacity specified by manufacturers on their websites, while other technical specifications are collected from the manufacturer or third-party websites. Electricity prices are based on the tariff orders of different Indian states. The tariff prices have been increased by 25% to approximate the final price being charged to the consumer, covering costs such as the land cost, parking fees, charger cost, etc. The electricity prices are increased at an annual rate of 1%, as we are not anticipating much increase in prices, thanks to the increasing penetration of cheap renewable energy in the grid. The battery replacement cost values are sourced from Bloomberg New Energy Finance (BNEF) (BNEF, 2020). The rate of increase is assumed to be 8 percent, based on an RMI estimate (Patil & Ghate, July 2020). Detailed information on the data type, parameters, and sources for EVs is summarised in Table 10.

Table 10: EV data type, parameters, and sources

Data Type	Parameters	Source
Upstream Emission Data	Criteria Pollutants (NOx, PM, SO_2, CO, HC	(Guttikunda & Jawahar, 2018)
	Carbon Emissions (CO_2)	(CEA, 2020)
	T&D Losses	(CEA, 2020)
	Methane (CH_4) and N_2O	(IPCC, 2018)
	Global Warming Potential	(IPCC, 2018)
Vehicle Specifications (Technical and Financial)	Price	Manufacturer websites; Third-party dealer websites (such as droom)
	Fuel Efficiency (km/kWh)	Estimated using battery capacity and range
	Costs (such as Depreciation, Finance, Tyre replacement, etc.)	Third-party dealer websites (such as droom)
	Battery Replacement Cost	(BNEF, 2020)

Key Assumptions

The useful vehicle life for both ICE vehicles and EVs is assumed to be 1,20,000 km. This is based on the estimates used in vehicle rating programmes of other countries. The fuel efficiency values are adjusted using an adjustment factor to account for the loss in fuel efficiency levels due to on-road conditions. This is mainly due to inconsistencies between on-road and test conditions in measuring fuel efficiency. Other rating systems also use an adjustment factor to bridge this gap. While there are no studies that provide an adjustment factor for the Indian conditions, based on a broader understanding of the discrepancy between test figures and on-road vehicle performance, it has been assumed that fuel efficiency is 30% lower on the road than in test conditions. A similar adjustment has been made in the case of EVs, where the fuel economy is adjusted by 30% to account for T&D losses, thermal losses, charger inefficiency, etc. A detailed discussion of these losses is provided in Step 5. The major inputs including insurance cost, tyre change cost, service cost, etc. needed for total cost of ownership calculation was obtained from third party website (Droom, 2020). For both EVs and ICE vehicles, the loan period is assumed to be 5 years, with an interest rate of 10 percent, based on secondary literature. The salvage value of EVs is roughly estimated to be 50 percent, as there is a scarcity of India-specific literature determining the useful vehicle life at the time of disposal. This also presents an opportunity for future research to come out with India-specific estimates on the salvage value of EVs and investigate deterioration factors and the discrepancy between test and on-road vehicle performance.

Step 2: Classification of Emissions Impact

In the second step, air pollutants and GHG emissions are classified in terms of their impact on health and the environment. In the GVR, health impacts are generated from local pollutants such as carbon monoxide, nitrogen oxides, hydrocarbons, and particulates. Breathing polluted air over a long period of time causes health issues and decreases life expectancy. This results in high economic costs at the national level, given the increased medical expenditure of households, loss in productivity due to illnesses, and loss in the workforce caused by early deaths.

Environmental impact is further divided into visibility impact, crop losses, and climate change impact (adverse effects of global warming). Both GHGs and air pollutants have environmental effects. GHGs create global and long-term effects that can mostly be controlled at the source, while air pollutants produce localised effects and visible changes.

Vehicle engines combust fuel (petrol, diesel, CNG, LPG), and the engine partially converts this energy to power the vehicle. In the process, pollutants (CO, HC, NOx, PM) and greenhouse gases (CO_2, CH_4, N_2O) are released through the tailpipe. While these emissions are a natural by-product of the fuel combustion process, the following three interdependent factors are largely responsible for excessive emissions that exceed the safe thresholds of ambient air quality and targets set for mitigating emissions, along with the overall magnitude of the emissions produced and damages accrued:

Source of emissions: The type of vehicle (light-duty vs. heavy-duty vehicles) and varying efficiency levels of engines and drive trains, along with the lifecycle phases covered in the calculation of emissions. GVR Phase II considers tailpipe emissions and upstream emissions, but the latter is limited to fuel production and distribution and does not include emissions released in fossil fuel extraction. Furthermore, end-of-life emissions are not considered.

- **Fuel use and fuel mix:** The type of fuel (petrol, diesel, CNG, LPG, electricity, renewable energy), and its quality, which is regulated by emissions norms. Diesel-powered vehicles have a substantially higher negative environmental impact than vehicles running on other fuels. For instance, chassis dynamometer testing carried out by the International Council for Clean Transportation (ICCT) and Centre for Science and Environment (CSE) in Delhi demonstrated that diesel-powered sport utility vehicles (SUVs) produce NOx emissions equivalent to those of 25-65 small petrol cars (ICAT, 2017).
- **Locational conditions:** Topographical, climatic, demographic, and socioeconomic conditions (increased private vehicle ownership, growing infrastructural mobility needs, age distribution), and regional and national policies such as fuel efficiency standards and emissions norms.

  The seriousness of the problems associated with air pollution and climate change in India is writ large. Enabling consumers to understand the negative impacts of their vehicle purchase on their individual health and well-being, as well as the local environment and economy, can help address the urgent need to control vehicular criteria pollutants and GHGs. To build consumer understanding, GVR accounts for two classes of impacts: public health and environmental, which are explained in the text below.

Public health impacts: Prolonged inhalation of air pollutants (NOx, CO, HC, and PM in the GVR) generated by fuel combustion in vehicles results in health damages and slowly increases the morbidity levels in the population, leading to early deaths and high associated economic costs. These pollutants get concentrated near busy roads, where population densities are high (WHO, 2018). Ailments due to air pollution include respiratory illnesses, cardiovascular disease, and other chronic illnesses, also known as Non-Communicable Diseases (NCDs), which account for 71% of deaths every year globally (EPA, n.d.). For instance, inhalation of an excessive amount of carbon monoxide blocks oxygen supply to the heart and brain (EPA, n.d.). High concentrations of NOx, a precursor of secondary particulates, cause irritation in the oral cavity and bronchial tubes, lead to coughing and shortness of breath, and exacerbate asthma (WHO, 2003). Children and the elderly are the most vulnerable to the health impacts of air pollutants.

Environmental impacts: These impacts include adverse effects from global warming due to GHGs (CO_2, CH_4, and N_2O). Human activities dependent on the burning of fossil fuels produce CO_2, which is the most significant heat-trapping gas that accelerates the natural GHG effect. This leads to excessive increases in temperatures and environmental damage. Methane, another heat-trapping gas, is the second most significant contributor to climate change. Globally, the transport sector accounts for nearly a quarter of energy-related carbon emissions. The impacts of global warming include extreme heat, rising sea levels, and irregular weather patterns. There is also a consensus among scientists worldwide that GHGs deteriorate human health through vector-borne diseases and water-related illnesses (WHO, 2003). Other environmental impacts include reduced visibility due to a haze in cities and crop and vegetation losses due to NOx, HC, and VOCs. While both GHGs and air pollutants produce environmental effects, the former create global and long-term effects that are difficult to control unless this is done at the time of release from the source, whereas air pollutants produce localised and immediately visible problems.

Air pollutants such as NOx, CO, HC, and VOCs also serve as indirect GHGs. However, indirect GHGs account for less than 1% of the total material impact in a warmer climate. Hence, in the GVR, the indirect climate impacts of air pollutants have not been considered. The impacts of air pollutants and GHGs that are accounted for in the GVR are summarised in Figure 5.

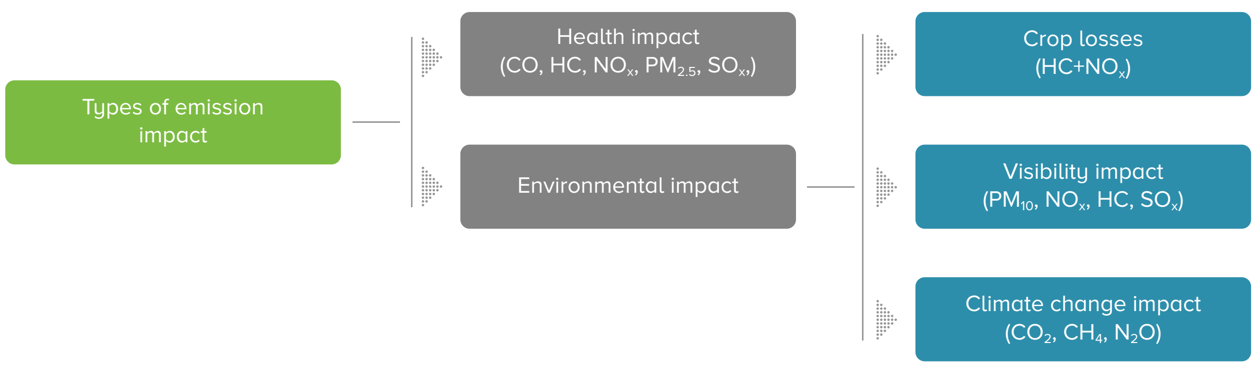


Figure 5: GHGs and air pollutants impacts covered in GVR

Step 3: Monetisation

For consumers to appreciate and purchase clean, efficient vehicles, they need straight forward information on different vehicle models' energy consumption, environmental costs, and economic benefits. While bringing this information to the foreground seems to be one of the most apparent required policy interventions to address the significant risks of energy-related pollution in India, there is still a shortage of information available to consumers to help them weigh the economic benefits of vehicles against their health-related and environmental impact. GVR facilitates this by translating the effects of air pollution and greenhouse gas emissions into economic terms, by ascertaining the monetary value of vehicles' impact on human health, climate, and environment per kilometre (₹/km).

Impacts from criteria pollutants and GHG emissions, both from upstream and tailpipe emissions, have been quantified in monetary terms in the GVR using a damage cost method as mentioned previously. This method reflects the damages and risks (losses to health, visibility, and crops) estimated in terms of costs per unit (g, kg, tonne) of air pollutants.

The Social Cost of Carbon (SCC)[1] and marginal damage cost is sourced from secondary literature, as original calculations were not part of the project scope. International vehicle rating programmes have benefitted from region-specific research studies and government-led projects to determine the damage cost or social cost factors of vehicular environmental externalities. In motor vehicle use, social costs include under-priced costs due to air pollution and external and non-market costs. Data-proficient governments use these cost factors to establish the cost-to-benefit ratios of energy and environmental regulations. Hence, they have quantitative analytics readily available for policymakers, researchers, and the general public that support the creation of information programmes such as vehicle rating and fuel efficiency labelling. For example, the European Commission ExternE project quantifies the external costs of energy consumption in carbon-intensive sectors such as transportation for member countries. These estimates have been used in Belgium's Ecoscore and UK's Next Green Car rating systems. Similarly, the ACEEE GreenerCars initiative used the social cost estimation by McDeluchhi and the GREET model. McDeluchhi et al (2000) estimated the social costs of motor vehicles based on air pollution impacts on health, visibility, and agricultural yield.

Calculating the damage cost factors from air pollutants in India: In the case of India, there is a dearth of studies estimating the cost of environmental externalities, particularly concerning air pollution. Sengupta and Mandal (2002) remain the only working paper produced in India that derives the health damage costs of air pollution from motor vehicles in India. Although this paper is based on secondary data from McDeluchhi et al., it provides a 'Benefit-Transfer Method' to derive India-specific estimates to fill the gap in primary analysis on the marginal costs associated with the environmental and public health impacts of vehicular emissions in India. This method enables the adaptation of the results at a regional level, considering region-specific factors such as demographics, population density, purchasing power parity, etc. To execute the Benefit-Transfer Method, Sengupta and Mandal (2002) made adjustments based on variations in the Gross Domestic Product (GDP), Purchasing Power Parity (PPP), per capita income, and population density in India (Sengupta & Subrata Mandal, 2002). In GVR Phase I, damage cost factors was validated by conducting an in-person interview with Professor Ramprasad Sengupta, Professor Emeritus of Economics, Jawahar Lal Nehru University, and his insights have also been incorporated.

To calculate the marginal damage costs of air pollutants in 2019, GVR adapted the four corrective steps Sengupta and Mandal (2002) applied to the marginal damage costs estimated by McDelucchi et al. (2000). The steps adopted are as follows and are summarised in Figure 6:

Step 1: First, marginal damage cost values are adjusted for inflation by converting them to 2019 prices using the United States (US) GDP deflator sourced from the World Bank database and converting them into Indian rupees using the Reserve Bank of India's (RBI) 2019 exchange rate.

Step 2: Second, the values are adjusted for the difference in purchasing power parity between India and the US. The values are multiplied by the PPP USD dollar (USD)-Indian rupee (INR) exchange rate sourced from the World Bank database.

Step 3: Third, to adjust for the variation in per capita income between the US and India, the ratio of per capita income in India to that in the US in PPP USD in 2019 is used.

Step 4: Fourth, the values obtained in Step 3 are adjusted for the variation in the size of the exposed population to the pollutants by using the ratio of the average population density of India to that of the US, sourced from the World Bank database.

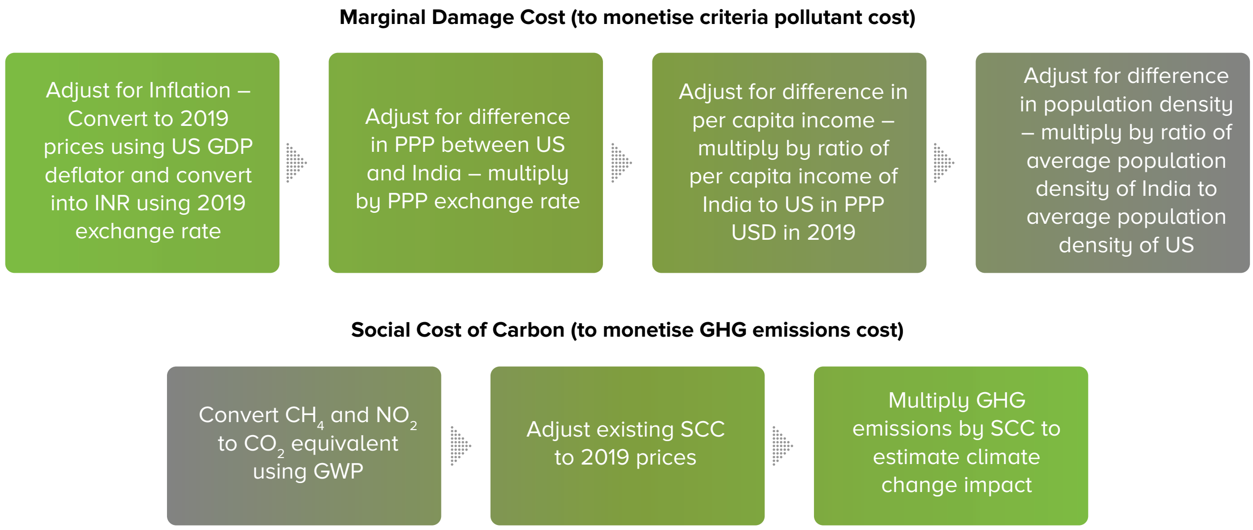


Figure 6: Key GVR rating calculation steps

For EVs, the marginal damage cost of upstream emissions is lower than that of ICE vehicles, due to the quantum of upstream emissions being produced. However, the factor of adjustment is considered the same for both the categories attributing to the fact that both refineries and thermal power plants are located in places with lower population density. To estimate the damage cost, the calculated marginal damage cost values were reduced by a factor of 10 to adjust for the difference in the exposed population based on a study by McDeluchhi et al. (2000).

Impacts from GHGs (CO_2, CH_4, N_2O) are monetised using the SCC method. SCC is a monetary estimate of the damages to health, the ecosystem, agricultural productivity, and other negative contributions caused per tonne of carbon dioxide equivalent released in a given year. Globally relevant SCCs have been calculated by various national governments and scholars in climate economics for the assessment of climate policies. In GVR Phase I, three main models were studied:

- William Nordhaus's model - Dynamic Integrated Climate and Economy (DICE)
- Richard Tol's model - Climate Framework for Uncertainty, Negotiation, and Distribution (FUND) - used extensively by IPCC
- Chris Hope's model - Policy Analysis for GHG Effect (PAGE) - Cambridge University, used extensively by the Stern Review on the Economics of Climate Change.

In Phase II, an additional literature search has been carried out to find country-level SCCs (CSCCs). Country-level estimates can allow us to better understand regional impacts, which is crucial to the design of effective adaptation and compensation measures. Similar to previous Integrated Assessment models (DICE, PAGE), a study by Ricke et al. developed a framework to calculate country-specific SCCs (Ricke, Drouet, Caldeira, & Tavoni, 2018). It comprises a socioeconomic module, climate module, and discounts. In the socioeconomic module, the Shared Socioeconomic Pathways (SSP) concept uses GDP and population parameters to estimate emissions. In the climate module, a range of country-specific transient warming responses to incremental CO_2 emissions was determined by matching SSP emission profiles with the representative concentration pathways (RCPs) modelled in the Fifth Coupled Model Intercomparison Project (CMIP5) to estimate baseline warming. CSCCs were calculated using both exogenous and endogenous discounting. For conventional exogenous discounting, two discount rates were used, 3 and 5 percent. GVR Phase II uses the India-specific SCC from the study by Katharine Ricke et al. SCCs are adjusted to 2019 prices using the 2019 exchange rate between USD and INR To monetise emissions, GHG emissions are multiplied by their CO_2 equivalent using GWP and then multiplied by SCC.

Table 11: Marginal Damage Cost for vehicle air pollutants in India

Pollutants	Marginal Visibility Costs (INR/km)			Marginal Health Costs (INR/km)			Marginal losses to crop (INR/km)		
	Low cost Estimate	High cost Estimate	Geometric Mean of Estimate	Low cost Estimate	High cost Estimate	Geometric Mean of Estimate	Low cost Estimate	High cost Estimate	Geometric Mean of Estimate
CO	0.00	0.00	0.00	0.00	0.02	0.00	0.00	0.00	0.00
HC	0.00	0.01	0.00	0.02	0.22	0.07	0.00	0.00	0.00
NOx	0.03	0.17	0.07	0.24	3.54	0.93	0.00	0.00	0.00
PM10	0.06	0.59	0.19	2.09	28.48	7.71	0.00	0.00	0.00
SOx	0.14	0.60	0.29	1.46	13.81	4.49	0.00	0.00	0.00
HC + NOx	0.00	0.00	0.00	0.00	0.02	0.01	0.03	0.04	0.04

Source: Author's Calculation

Note: For upstream emissions, the values are reduced by a factor of 10 due to differences in the exposed population.

Step 4: Normalisation

In the next step, the reference vehicle model is selected for the process of normalisation. The environmental and health damage costs of each model are normalised against the environmental and health costs of a 'Reference Vehicle'. The normalisation approach has been used in Belgium's Ecoscore and UK's Next Green Car (NGC) rating programmes (Next Green Car, 2016). Ecoscore uses a clean vehicle with Euro 4 standards (the methodology report was published in 2012), and NGC uses a highly polluting vehicle as a reference.

In GVR, normalisation against a reference vehicle produces two dimensionless values – the environmental rating and air pollution rating - for each model, as shown in Box 3. These two values are added together to create the 'Damage Score'. The reference vehicle is an ideal vehicle with a Damage Score of 1. The less deviant a vehicle is from this score, the lower are its negative impacts. In GVR Phase I, the model complying with BS-VI emissions norms was considered a reference vehicle, as vehicles considered for rating were manufactured in 2017 and follow BS-IV emissions norms. From April 2020 onwards, only BS-VI compliant vehicles have been sold on the market. Therefore, we cannot consider the BS-VI vehicle model as a reference model, as we did in the last phase. Furthermore, in Phase I, a single reference model was used for all types of two-wheelers and three-wheelers, irrespective of their engine size. This can penalise a motorbike with a larger engine, as the fuel economy of such motorbikes is lower than that of motorbikes with smaller engines.

Therefore, in Phase II, two-wheelers are categorised into different slabs based on the ICE engine size or EV battery capacity. After that, a reference vehicle is used as a benchmark for each category. The reference vehicle is the cleanest variant that can possibly exist in the respective slab. This reference vehicle will thus have the best-achieved fuel economy and lowest criteria pollutants emitted in that slab. GHG emissions are estimated based on the reference model's fuel economy. In the future, as other models are added to the GVR, the reference model will need to be upgraded.

Step 5: Cost and rating calculations

The final step is the calculation of the real cost of ownership and GVR ratings of the models. For EVs, we first estimate the battery's actual energy consumption to calculate the emissions. Energy losses occur when transmitting electricity from power plants to vehicle batteries and then to wheels. According to the Central Electricity Authority, India's T&D losses were around 21.04% in 2017-18 (CEA, 2020). Other losses occur due to charger inefficiency, thermal losses, etc. Therefore, to account for these losses, we have increased the battery consumption by 30% to calculate the actual energy consumption and emissions. Other associated assumptions for cost calculations relating to EV and ICE two-wheeler models have been disclosed in the annexure VI. The emissions calculation for EVs is discussed in Box 1.

Battery actual energy consumption (kWh)	=	Battery capacity/ (1-losses*)
Fuel economy (km/kWh)	=	Range (km) / Battery actual energy consumption (kWh)
Mass of criteria pollutants or GHG emissions (g/km)	=	Emission factor (g/kWh) / Fuel economy (km/kWh)

Note:
*30% includes T&D losses (21.04%), charger efficiency, thermal losses, etc.

Box 1: EV emissions calculations

For ICE, the mass of criteria pollutants is directly taken from Form 22, as discussed in Step 1. After deriving the emissions in g/km for both ICE vehicle and EV models, each criteria pollutant mass is multiplied by the marginal damage cost (discussed in Step 3) for that pollutant, given in /g. For GHG emissions, all the emissions are converted into CO_2 equivalent and then multiplied by the SCC, as shown in Box 2.

Cost Calculation for EVs/ICE

Cost of criteria pollutants (₹/km)	=	Mass of criteria pollutants (g/km) * Marginal damage cost of criteria pollutant (₹/g)
Mass of CO_2 equivalent (g/km)	=	Mass of GHG emissions (g/km) * GWP
Cost of GHG emissions** (₹/km)	=	Mass of CO_2 equivalent (g/km) * Social Cost of Carbon (₹/g)

Note:
**Emissions include GHG (CO_2, N_2O, CH_4) and criteria pollutants (NOx, HC, CO, PM, SOx)

Box 2: EV/ICE vehicle cost calculation

The health-related and environmental cost of each model is calculated by adding up the costs of criteria pollutants and GHG emissions (upstream and tailpipe emissions) for that model. The total health and environmental cost is called the composite damage cost and is expressed in INR per km. This cost is added to the standard 'Total Cost of Ownership' of that vehicle to calculate the 'Real Cost of Ownership'. The total cost of ownership is calculated as the sum of the vehicle upfront cost, financing cost, and operations and maintenance cost (such as fuel cost, service charges, tyre replacement cost, etc.), minus the salvage value. The details of the assumptions used for TCO calculations is available in annexure VI. In the case of EVs, we have also considered the central subsidy provided in the FAME II scheme, wherein two-wheelers and three-wheelers are eligible for a subsidy of INR 10000/kilowatt-hour (kWh), (MoHI&PE, 2019). Additionally, EVs are eligible to claim an income tax deduction on the interest paid on the vehicle loan for up to three years (Patil & Ghate, July 2020). Equations for the above mentioned calculations are provided in Box 3.

Health Cost (₹/km)	=	Cost of NO_x + Cost of HC + Cost of CO + Cost of PM + Cost of SOx
Environmental Cost (₹/km)	=	Climate Cost + Visibility Cost + Losses to Crop
• Climate Cost (₹/km)	=	Cost of CO_2 + Cost of CH_4 + Cost of N_2O
• Visibility Cost (₹/km)	=	Cost of HC + Cost of NO_x + Cost of PM + Cost of SOx
• Losses to Crop (₹/ km)	=	Cost of HC + NO_x
Composite Damage Cost (₹/km)	=	Health Cost + Environmental Cost
Total Cost of Ownership (₹/km)	=	Vehicle Cost + Interest Rate + Fuel Cost + Service Charges + Tyre Cost + Depreciation + Insurance Cost (+ Battery Replacement Cost for EVs) – Salvage Value – Subsidy (for EVs)
Real Cost of Ownership (₹/km)	=	Total Cost of Ownership (₹/km) + Composite Damage Cost (₹/km)
Health Rating	=	Health cost of vehicle / Health cost of reference vehicle
Environmental Rating	=	Environmental cost of vehicle / Environmental cost of reference vehicle
Damage Score	=	0.6*Health Rating + 0.4*Environmental Rating

Box 3: ICE and electric vehicle health and environmental cost, real cost of ownership and GVR rating calculations

The weighting factors assigned to the two impact categories reflect the regional priorities for urgent action to reduce air pollution's negative impact on human health and economic development. Therefore, the model's damage score comprises 40% of the environmental rating and 60% of the health rating. Finally, based on the damage score, vehicles are assigned a rating on a scale of 1-5, with 5 being the best and 1 being the worst. For example, the vehicle with a damage score of 1 is considered the cleanest vehicle and receives a GVR rating of 5. Every 0.5 value increase in the damage score, the vehicles' GVR decreases by an equal amount. Thus, the GVR is a function of the vehicles' damage score, underlining the environmental performance. Figure 7 is a process flow representation summarizing the calculation of damage score and real cost of ownership.

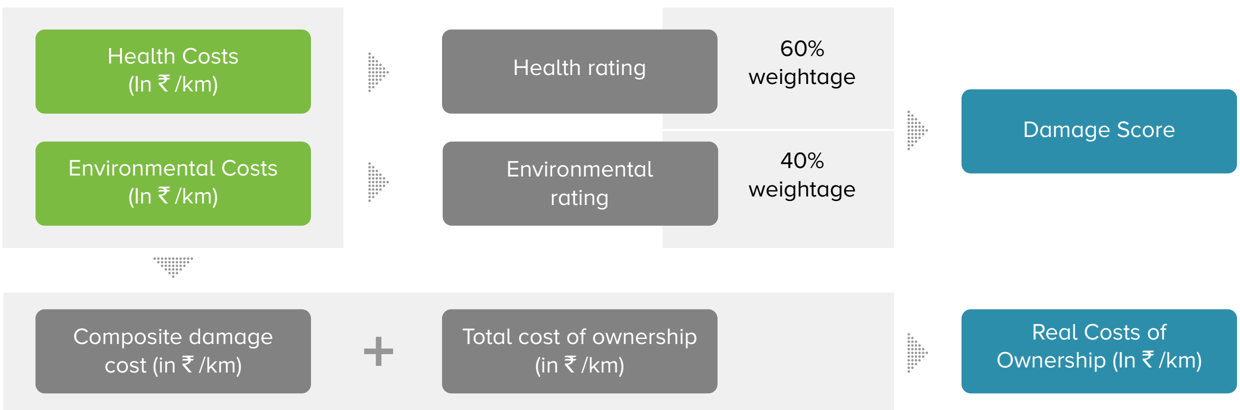


Figure 7: Summarises the relationships between the different costs and scores mentioned above

The next chapter discusses the results and insights from the second phase of GVR.

5. Results

After applying the steps in the methodology, the vehicle rating has been obtained separately for both ICE and EV variants. Additionally, during the process, other key results were obtained like Health damage costs, Environmental damage costs, Composite damage costs (CDC = health and environmental damage costs), Damage score, Total cost of ownership, Real cost of ownership (CDC +TCO) for every vehicle as can be seen in Annexure II & III. The results are also available on the GVR website for public consumption.

We were able to obtain data for 29 ICE variants and 33 EV variants. For ICE, both scooters and bike models were considered while only the former was available for the EV category. The samples considered are sufficient for us to draw meaningful insights about each category based on the key features presented in the tables. In this report, the names of actual vehicle models, OEMs have been masked to avoid any bias.

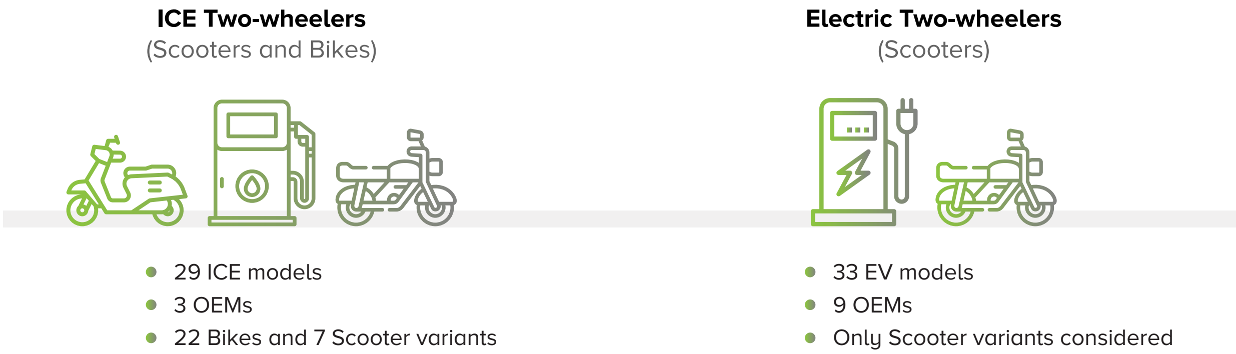


Figure 8: Details on 2-Wheelers considered in the Phase-II

Analysis of ICE Models

Due to the absence of Form 22 data on PM emissions for petrol vehicles, the health costs estimates for two-wheelers exclude the costs borne from PM emissions. Owing to the gravity of illness and increased medical expenditures, PM emissions were found to have the highest marginal damage costs out of all the criteria pollutants. But due to the absence of an official type-approval PM data in Form 22, its health damage cost has been left out from GVR. Hence, the health costs, and subsequently the composite damage costs, should be seen as a much conservative estimation of money lost to health damages for each km that a vehicle runs. Additionally, the mass of air pollutants for each vehicle has been sourced from Form 22, which declares the homologation data generated from type approval tests of vehicles. Hence, the declared pollutant level is dependent on the accuracy of the testing procedures and their convergence with the real-world driving conditions.

Table 12: Basic Statistical Description for ICE Models

Parameter	Mean	Median	Range (Max-Min)	Standard Deviation
Engine Capacity (cc)	137.5	124.6	152.8	35.9
Fuel Economy (km/l)	51.7	50	37	9.5

As can be seen from Table 12, the central tendencies of the dataset i.e. mean, median are almost overlapping. However, in terms of variability in the dataset, the range of engine capacity is way higher and hence is more variable. Even standard deviation also indicates that the values in engine capacity vary more around their mean whereas the values of fuel economy are more clustered.

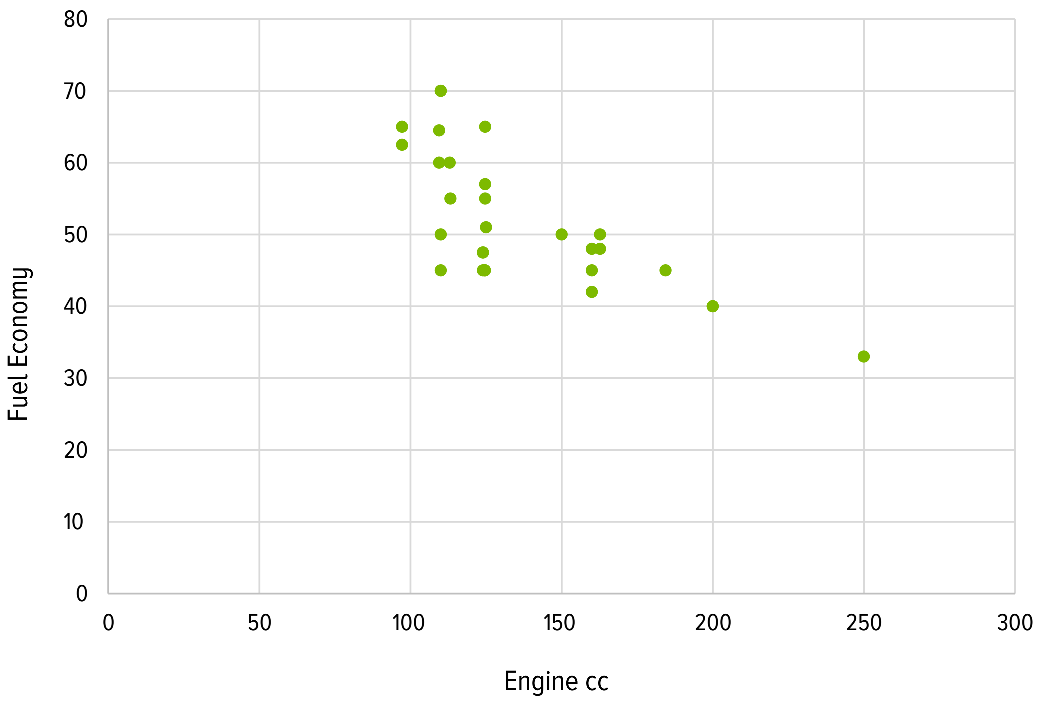


Figure 9: Fuel Economy v/s Engine cc for ICE Models

On analyzing the correlation amongst each of the parameters, we observed a few key insights. As seen in the scatter plot of Figure 9, the fuel economy of the vehicles has a negative correlation with engine capacity. This correlation can be extended to causality as the larger engine will combust more fuel with each revolution it turns in a minute (rpm) thus consuming more fuel than a smaller engine would, during the same journey.

The relationship of engine capacity with the real cost of ownership appears linear as seen in Figure 10. This linearity can be expounded by the fact that as the size of the engine increases, the cost associated with its manufacturing, control and reinforcement also increases. Moreover, with the increase in engine capacity, the fuel economy decreases thus increasing the total health and environmental damage cost associated with the vehicle.

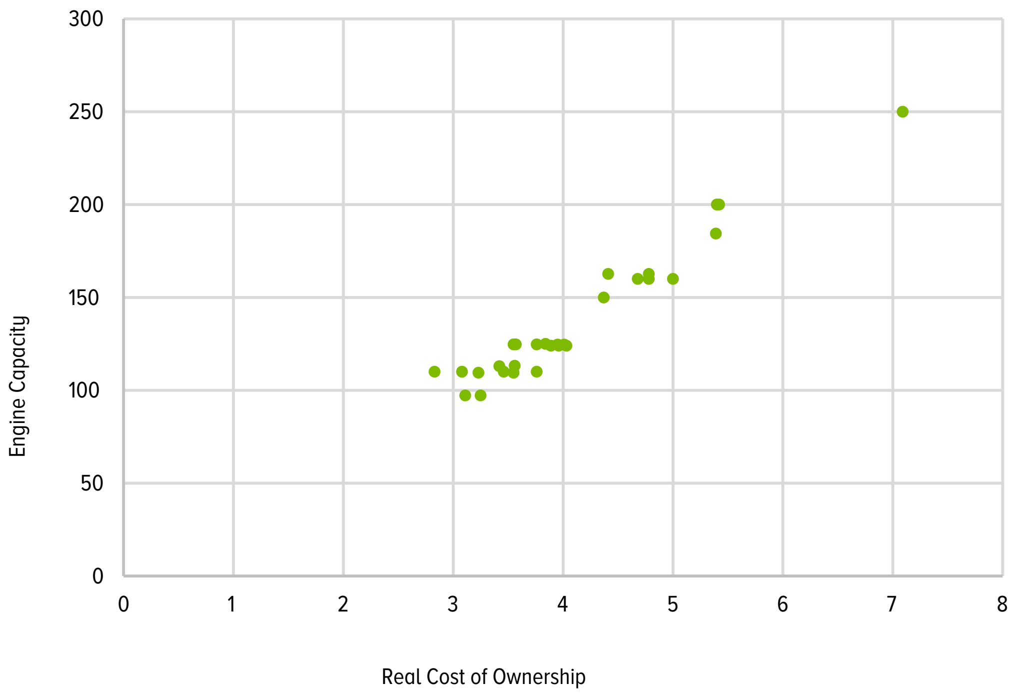


Figure 10: Engine Capacity v/s Real Cost of Ownership for ICE Models

Moving forward, we visualized the Composite Damage Cost (CDC) for all vehicle models and its division into its sub-components i.e. Total Health Damage Cost and Total Environmental Damage Cost as shown in Figure 11. The vehicle models ICE-B-7, 16, 17 have the lowest CDC attributed to low engine capacity and proportionately high fuel economy. On the flip side, ICE-B-4, 19, 21 have high CDC due to their high engine capacity and low fuel economy. Interesting to note here that the models having the lowest or highest CDC belong to the bike sub-category.

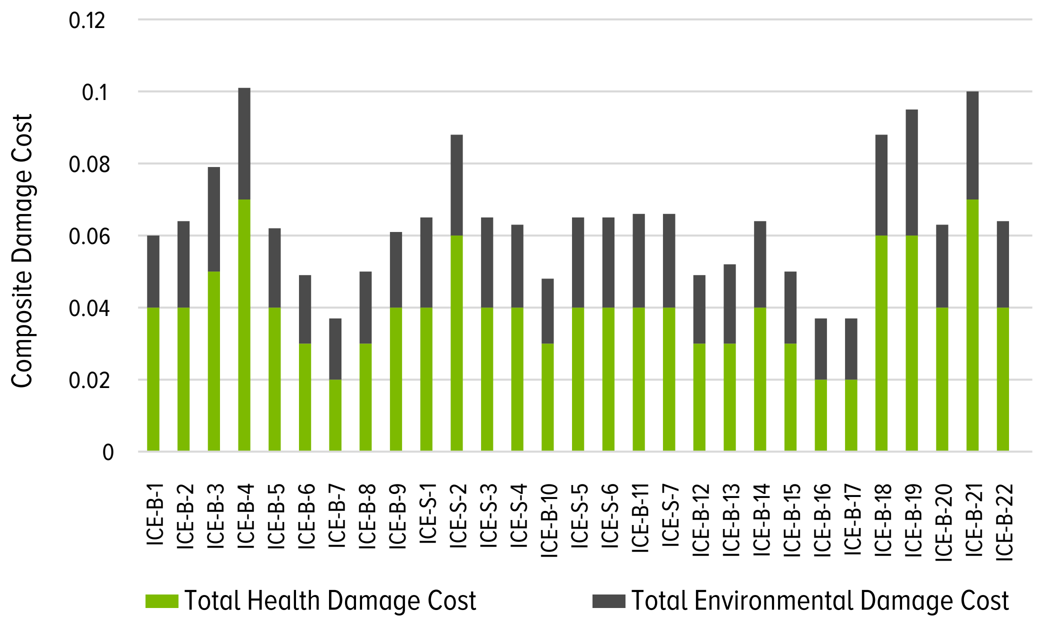


Figure 11: Stacked Bar Chart for Composite Damage Cost of ICE Vehicles

Advanced Analysis

While analyzing the dataset, we employed the outlier detection technique in order to find ICE models with behavior that is different from expectation. Box and Whisker plots present themselves as simple yet practical outlier detection methods. Any object that is more than 1.5 times of Inter-Quartile Range (IQR) smaller than the Q1 quartile or larger than the Q3 quartile is treated as an outlier because the region in between contains 99.3% of observations. After normalization, the box plot obtained for engine capacity and fuel economy is shown in Figure 12. The outlier in the engine capacity is ICE-B-19 with a 250 cc engine.

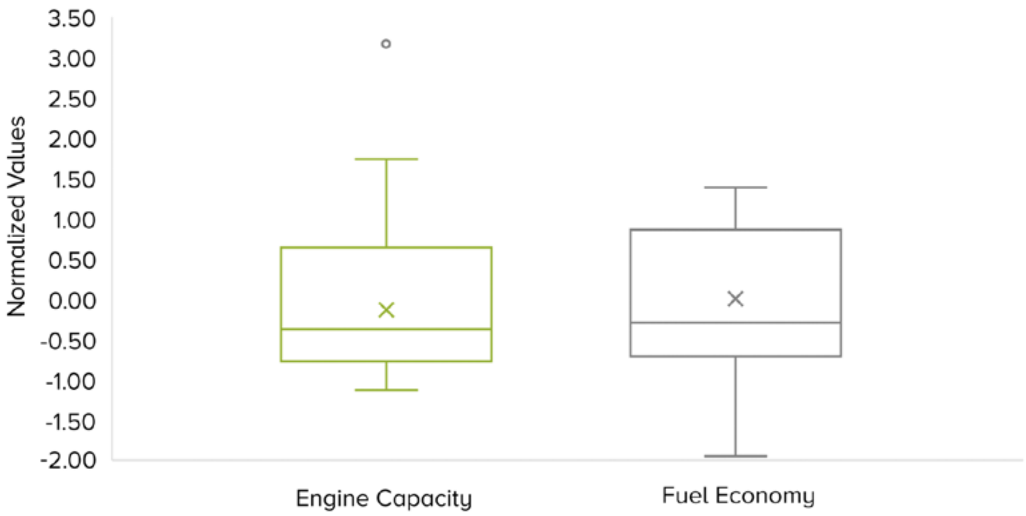


Figure 12: Box and Whisker plot for Engine Capacity and Fuel Economy

Furthermore, since each of the vehicle models is described by several parameters, we employed one of the dimensionality reduction techniques i.e. Principal Component Analysis (PCA) to construct a new space of lower dimensions instead of using subspaces of the original data. This is because the smaller datasets are easier to explore and visualize without extraneous variables to process. The new variables that are constructed are termed Principal Components (PCs). They are linear combinations of the initial variables. These combinations are done in such a way that the new variables are uncorrelated and most of the information within the initial variables is squeezed or compressed into the first few components. As seen in Figure 13, the principal components 1 and 2 capture approximately 88% of the variation in the dataset. Usually, 70% of total variability is a common, if subjective, cut-off point to decide the number of PCs to be retained for analysis.

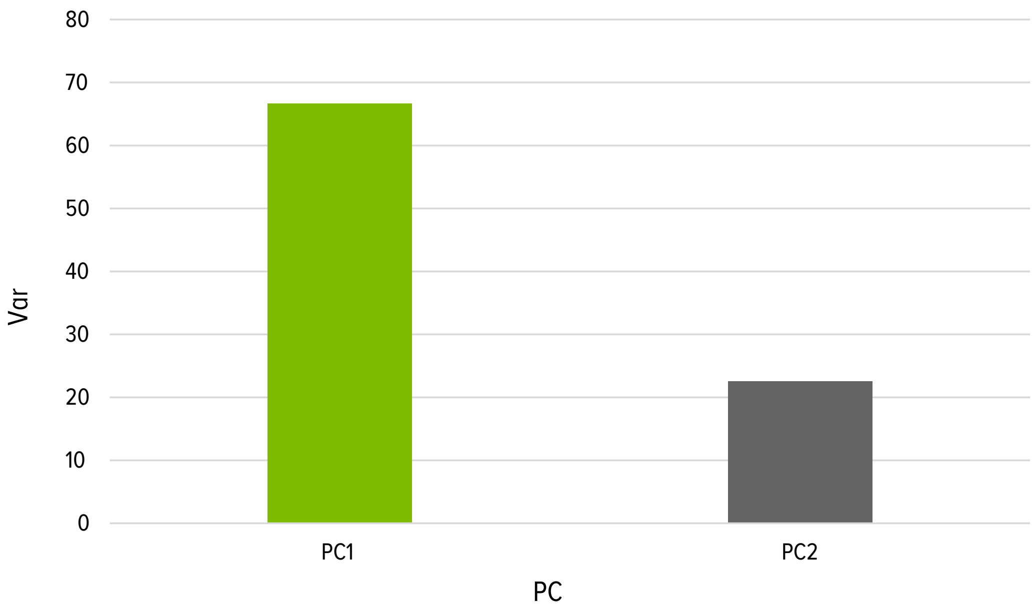


Figure 13: Scree Plot for Principal Components

A scatter plot between PC1 and PC2 can be observed in Figure 14. Such a plot brings out strong patterns from complex datasets. It can be seen that there are clusters in the dataset, such that the objects in a particular cluster are similar to one another, yet dissimilar to objects in other clusters.

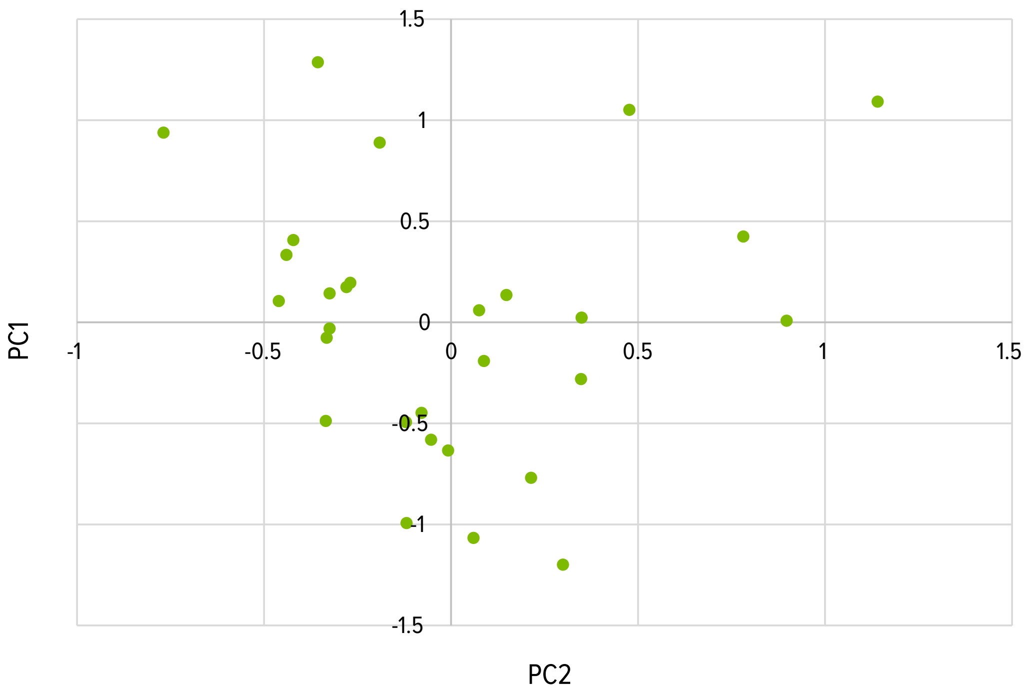


Figure 14: Scatter Plot PC1 v/s PC2 for ICE Models

Thus, a dendrogram on the dataset was developed to work out the best way to allocate models to clusters. From Figure 15, it can be manifested that 3 clusters will most suit the analysis. Using this knowledge, we employed an agglomerative clustering technique to classify each vehicle model to the respective clusters. Annexure IV provides the details on the clusters.

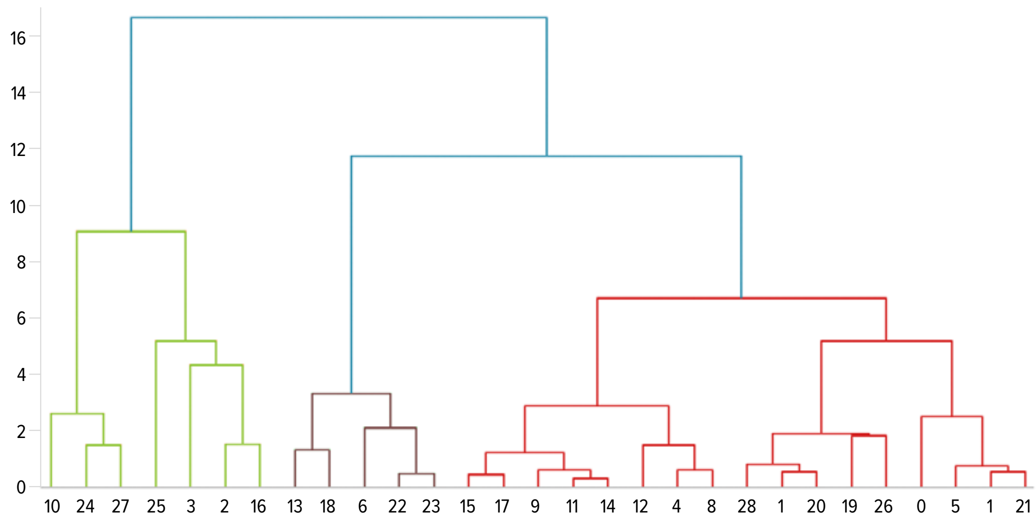


Figure 15: Dendrogram for ICE Models

Once the clusters are obtained, each formulated cluster can be regarded as a summary of data as seen in Table 13. **The rationale behind clustering the models is to compare newly incoming data to the formulated clusters to extract an early understanding of the model based on two crucial parameters i.e. Engine Capacity and Fuel Economy.**

Table 13: Cluster summary for ICE Models

Clusters	Average Engine Capacity (cc)	Average Fuel Economy (km/hr)	Efficiency	Health and Environmental Impact
Cluster 1	183	41	Low	High
Cluster 2	127	51	Medium	Moderate
Cluster 3	110	67	High	Least

Analysis of EV Models

The EV two-wheeler sales market in India has seen a significant increase over the last five years. The sales figures have jumped from a mere 20,000 units in FY 2015-16 to a substantially higher 1,52,000 units in FY 2019-20 (Society of Manufacturers of Electric Vehicles, n.d.). Correspondingly, EV data comprising the technical specifications of the respective models have become more accessible. The EV policy space has also been dynamic, with regular updates on EV schemes and allied subsidies that have set the tone for an EV-ready India.

An interesting aspect that is inferred from the analysis is with respect to the subsidy offered in FAME-2. Recently, the scheme was amended to introduce an incremental subsidy on a per kWh basis for e-2 Wheelers (Department of Heavy Industries, 2021). However, our analysis reveals that the best-in-class fuel economy was not achieved by the vehicle with the highest battery capacity. This is a vital insight for the policymakers to move beyond the idea of extending subsidies based on battery capacity alone. The parameters for subsidies need rethinking in order to realize the demand incentive potential.

Table 14: Basic Statistical Description for EV Models

Parameter	Mean	Median	Range (Max - Min)	Standard Deviation
Battery Capacity (kWh)	1.73	1.56	2.34	0.60
Fuel Economy (km/ kWh)	34.38	35	35.8	7.39

Table 14 captures the central tendencies and variability of parameters associated with EV models included in GVR Phase-II. As observed, the mean and median values for two critical parameters, battery capacity and fuel economy, are almost overlapping. However, the fuel economy of the models varies across a significant range of 35.86 km/kWh, which reflects the eclectic models available in the market today.

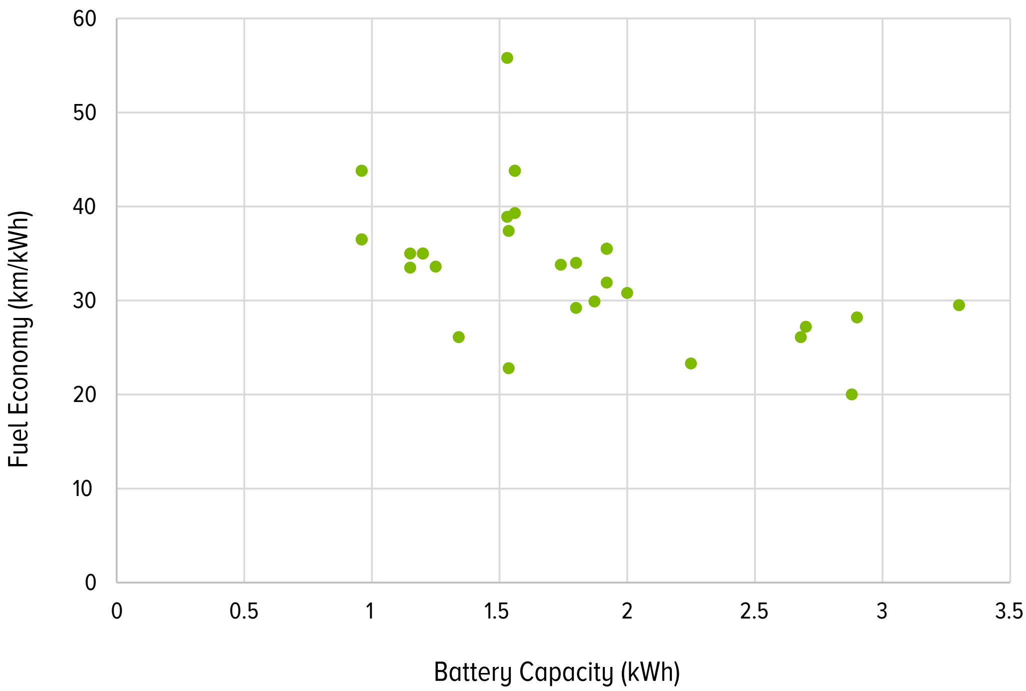


Figure 16: Battery Capacity v/s Fuel Economy for EV Models

On analyzing the correlation among each of the parameters, we observed a few key insights. As seen in the scatter plot of Figure 16, the fuel economy of the vehicles has a negative correlation with battery capacity. This can arise due to the fact that the larger battery in a vehicle will have a higher deadweight and reinforcement weight to be carried around in the trip. Although, the fuel economy of the vehicle will depend on several other features like aerodynamics, auxiliaries impact, etc.

The relationship of battery capacity with the real cost of ownership appears linear as seen in Figure 17. This linearity can be expounded by the fact that as the size of the battery increases, the associated cost also increases. Moreover, with the increase in battery capacity, the fuel economy decreases thus increasing the total health and environmental damage cost associated with the vehicle.

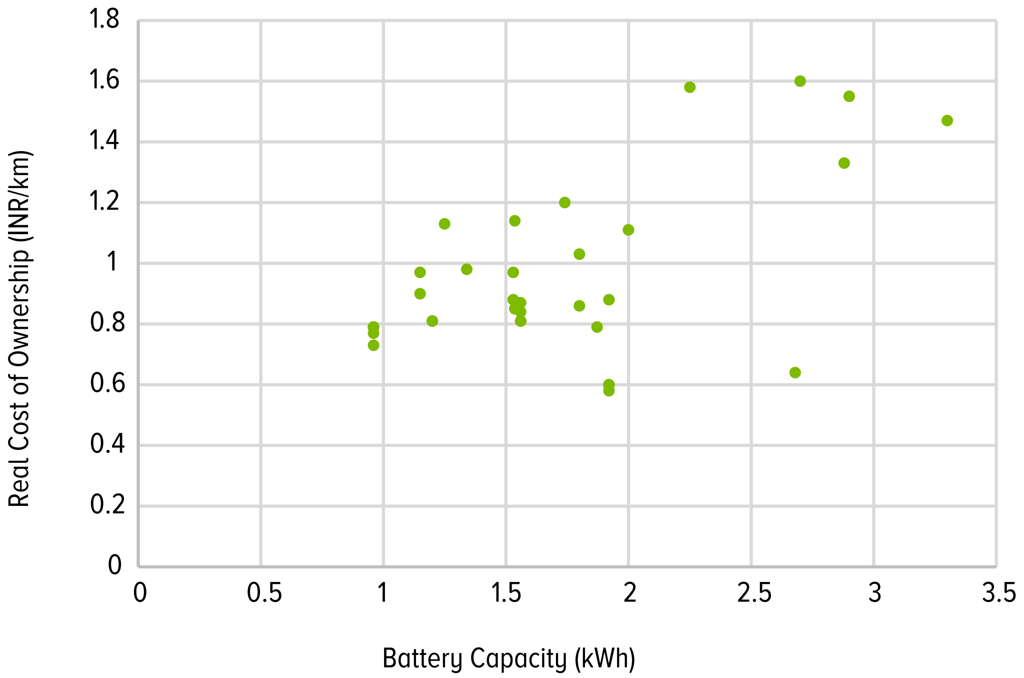


Figure 17: Battery Capacity v/s Real Cost of Ownership for EV Models

Figure 18 visualizes the Composite Damage Cost (CDC) for all vehicle models and its division into its sub-components i.e. Total Health Damage Cost and Total Environmental Damage Cost. Two critical insights emerge from this visual. First, EVS-11 has the lowest CDC, although it doesn't have the lowest battery capacity on the list. This is mainly attributed to the highest fuel economy in the lot. Second, EVS-7 has the highest CDC, irrespective of not having the highest battery capacity on the list. This is mainly attributed to subpar fuel economy in comparison to other counterparts having similar battery capacity.

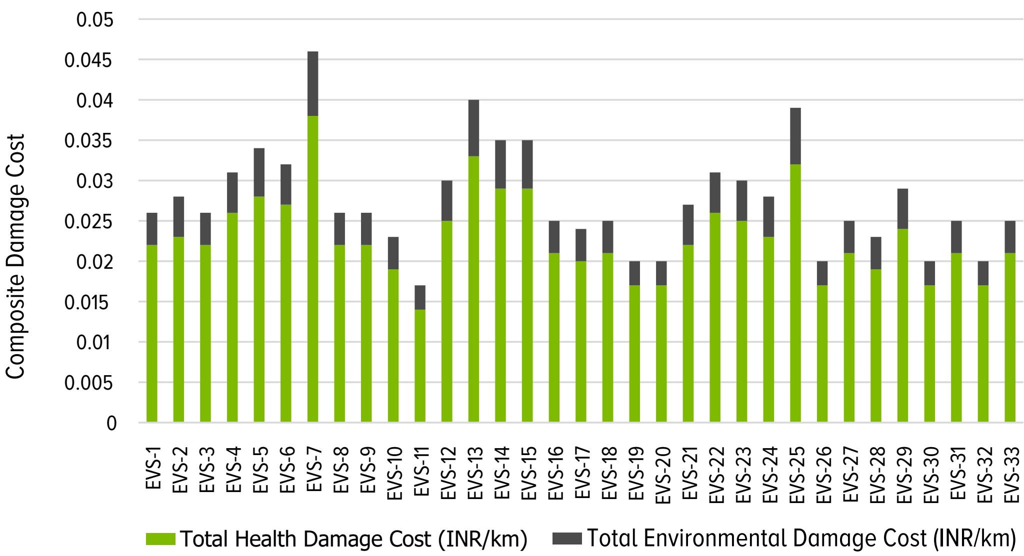


Figure 18: Stacked Bar Chart for Composite Damage Cost of EV models

Advanced Analysis

While analyzing the dataset, we employed an outlier detection technique in order to find EV models with behavior that is different from expectation. Box and Whisker plots present themselves as simple yet practical outlier detection methods. After normalization, the box plot obtained for battery capacity and fuel economy is shown in Figure 19. EVS-22 with 3.3 kWh battery capacity is an outlier along with EVS-11 with a 55.82 km/kWh fuel economy.

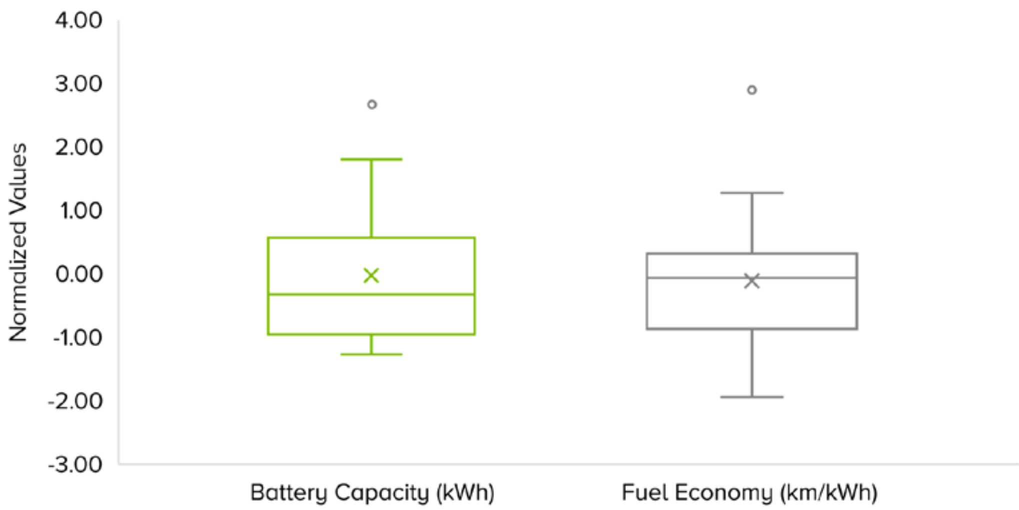


Figure 19: Box and Whisker plot for battery capacity and fuel economy

Furthermore, Principal Component Analysis (PCA) was applied to construct a new space of lower dimensions. As seen in Figure 20, the principal components 1 and 2 capture approximately 84.2% of the variation in the dataset which is higher than 70% of the total variability norm considered as the subjective cut-off point for the analysis.

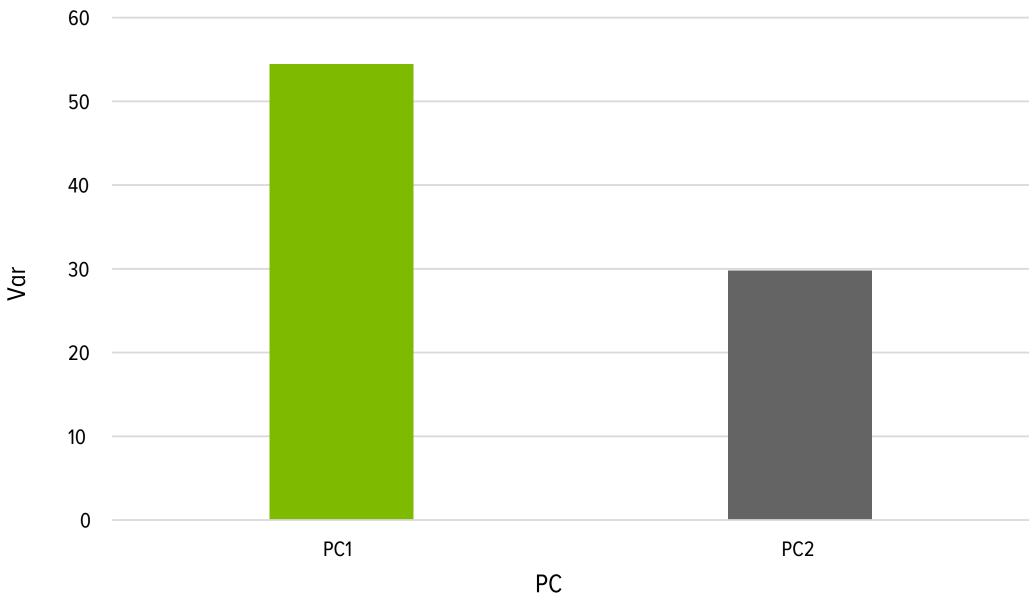


Figure 20: Scree Plot for Principal Components

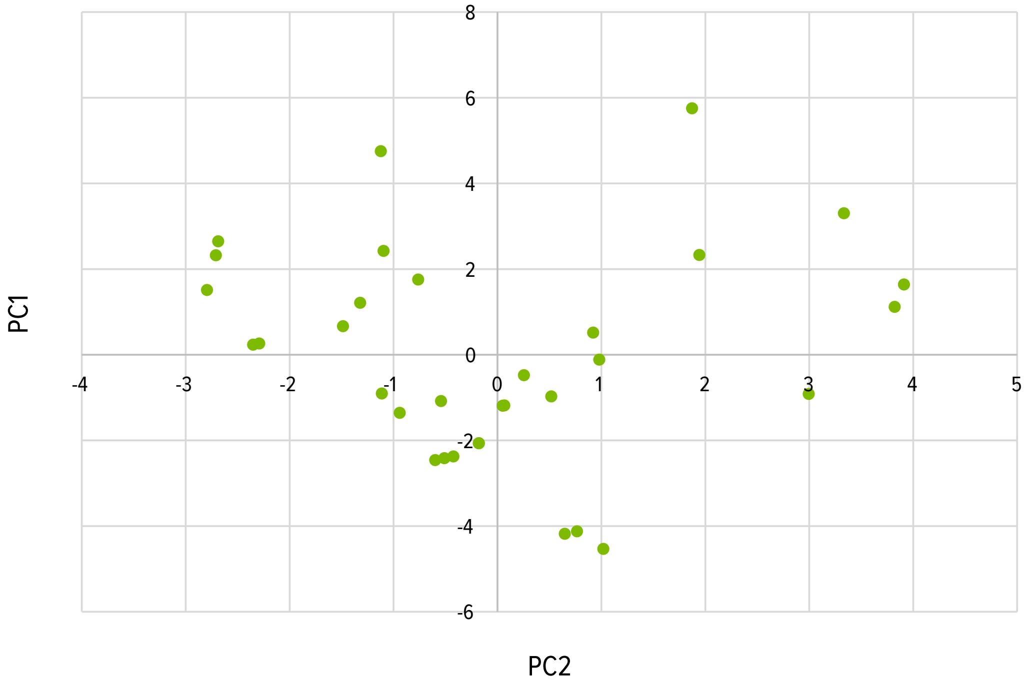


Figure 21: Scatter Plot PC1 v/s PC2 for EV Models

A scatter plot between PC1 and PC2 can be observed in Figure 21. Such a plot brings out strong patterns from complex datasets. It can be seen that there are clusters in the dataset such that the objects in a particular cluster are similar to one another, yet dissimilar to objects in other clusters.

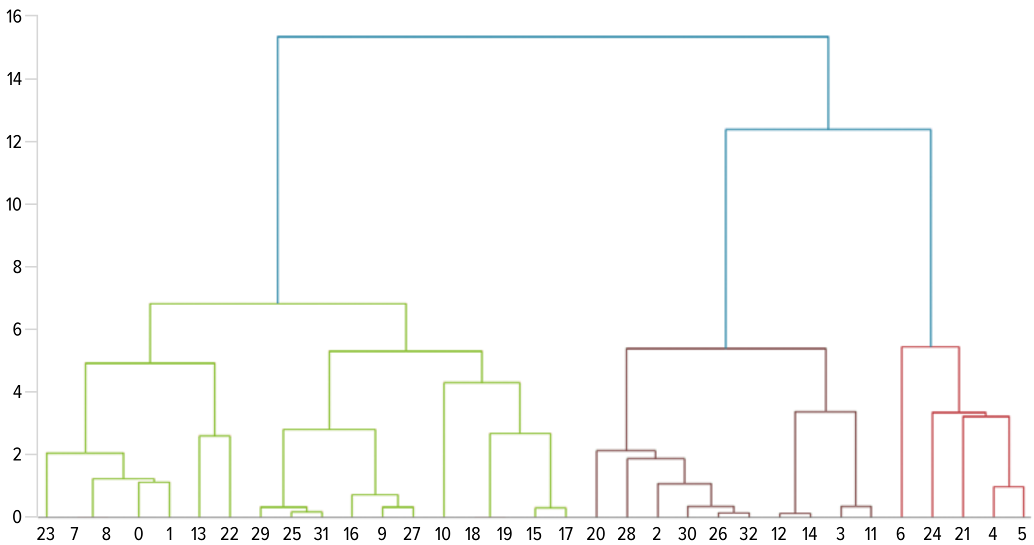


Figure 22: Dendrogram for EV Models

A dendrogram was created on the dataset to work out the best way to allocate models to clusters. From Figure 22, it can be inferred that 3 clusters will most suit the analysis. Using this knowledge, we employed agglomerative clustering to classify each vehicle model to the respective clusters. Annexure V provides the details on the clusters.

Once the clusters are obtained, each formulated cluster can be regarded as a summary of data as seen in Table 15. **The rationale behind clustering the models is to compare**

newly incoming data to the formulated clusters to extract an early understanding of the model based on two crucial parameters i.e. Battery Capacity and Fuel Economy.

Table 15: Cluster summary for EV Models

Clusters	Average Battery Capacity (kWh)	Average Fuel Economy (km/kWh)	Efficiency	Health and Environmental Impact
Cluster 1	1.40	38.44	High	Least
Cluster 2	1.87	30.39	Medium	Moderate
Cluster 3	2.78	27.07	Low	High

Comparative Assessment of ICE and EV Models

We compared ICE and EV models based on several parameters like Fuel Economy, Total Health Damage Costs, Total Environmental Damage Costs, Composite Damage Costs, etc. Of these parameters, the unit of fuel economy measure is different for the two categories. The ICE fuel economy is expressed in kilometers per liter (km/l) whereas the EV fuel economy is expressed as kilometers per kiloWatt-hour (km/kWh). To arrive at a uniform unit of measurement, fuel economy in terms of kilometers per megajoule (km/MJ) was deduced.[2]

Table 16 represents the average values of the aforementioned parameters for each of the vehicle categories. It can be observed that the fuel economy of EV models is around 6 times better than the ICE counterparts. The average damage score for EVs is around 1.38 which is substantially lower than the ICE value of 2.08. This **clearly cements the fact that EVs have minimal impact on human health and environment**. The comparison of CDC and its sub-components across ICE and EV models can be seen in Figure 23. CDC is higher for ICE models, due to high values of both health and environmental damage costs.

Table 16: Average Parameter Values for ICE and EV Models

Parameters	EV	ICE	Remarks
Average Fuel Economy (km/MJ)	9.55	1.64	EVs are 6 times more fuel-efficient than ICE vehicles
Average Total Health Damage Cost (INR/100 kms travelled)	2.3	4.03	EVs have half the health damage cost than ICE vehicles
Average Total Environmental Damage Cost (INR/100 kms travelled)	0.45	2.41	Environmental damage cost of EVs is negligible
Average Composite Damage Cost (INR/100 kms travelled)	2.78	6.31	CDC of EVs is half of the ICE counterparts
Average Real Cost of Ownership (INR/100 kms travelled)	96	411	Real cost of ownership for ICE is 4 times higher than EVs
Average Damage Score	1.38	2.08	Damage score of EVs is nearly half of ICE vehicles

[2] 1 kWh = 3.6 MJ and 1 Liter of Gasoline = 31.53 MJ

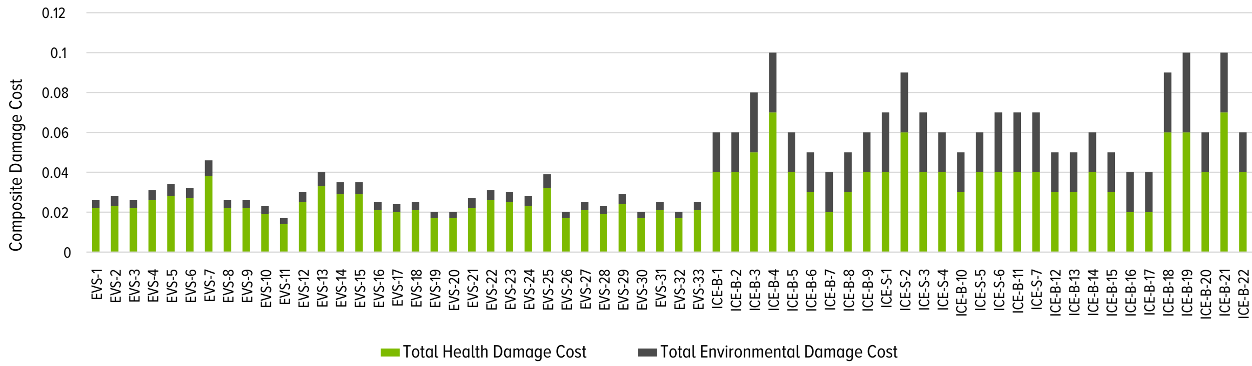


Figure 23: Composite Damage Costs of All Models considered in GVR Phase-II

The next section discusses the way forward for the GVR program.

6. Way Forward

India is amongst the few countries across the world that are attempting to simultaneously improve the availability, affordability, and sustainability of the transport sector. In order to promote fuel-efficient vehicles, there is a need for a confluence of demand and supply-side interventions. With a slew of supply-side interventions from the government, the importance of a consumer information tool in achieving greener transport becomes paramount. GVR is India's only vehicle rating system based on vehicles' environmental performance. GVR allows consumers to identify the cleanest and most economically sensible vehicle models from an available pool. It provides consumers web-based access to easy-to-understand information- in monetary terms- so they can make informed purchase decisions, and enables them to see the costs and benefits of owning greener vehicles.

However, there are still certain technical and regulatory facets that require attention in order to polish the GVR beyond its current stage. A comprehensive set of future areas of work and policy level recommendations are highlighted below based on the learnings from the current phase of the GVR program.

Technical Facets

1. **Social Cost of Carbon (SCC)**: The SCC is an important element used in the GVR methodology to determine the health and environmental damages caused due to carbon dioxide equivalent emissions. While GVR in its second phase has utilized the latest research determining the Country-level Social Cost of Carbon (CSCC) (Ricke, Drouet, Caldeira, & Tavoni, 2018), specific estimates for India are unavailable. As research on the SCC evolves, India must work out its own SCC estimate that is contextualized to the local carbon emission scenario. An optimum SCC can strike the balance between carbon-intensive sectors such as transport, manufacturing industries, and carbon footprint reduction goals (ZailiZhen, 2018).

2. **Grid emission factor**: Plant-to-Wheel emission considerations are necessary to equally weigh the environmental performance of ICE and EVs. Given that EVs have zero tailpipe emission, the emissions at the power plant are considered. With rapid additions of renewable energy capacity to our power mix, the grid emission factor must be upgraded consistently (JulesChuang, 2018). Improving the grid emissions factor will further impact the environmental performance of EVs and will pitch them as more favourable.

3. **Damage cost estimation**: Upstream emissions from ICE vehicles are considered as part of the Plant-to-Wheel emissions. Similarly, electric vehicles have power plant emissions considered as part of the damage cost calculations. Both the refineries (in case of ICE) and the power plants (in case of EV) are geographically situated in low population density regions. Thus, in order to account for the emission impact in the cities, assumptions based on a paper by McDeluchhi et al (2000) can be considered. Moving forward, other studies must be explored to develop estimation factors, considering that newer economic models might provide a more accurate framework for assumptions.

4. **Vehicle performance degradation**: Currently, the GVR methodology assumes that the fuel economy and emission parameters of a vehicle are consistent throughout the life of the vehicle, assuming it to be 10 years. However, an increase in vehicle age has been found to have a direct correlation with degradation in vehicle emission control systems resulting in increased emissions (JensBorken-Kleefeld, 2015). In future iterations, this drop in vehicle performance must be incorporated into the Total Cost of Ownership (TCO) and Real Cost of Ownership (RCO) calculations of the vehicle models.

5. **Vehicle segment and its population**: GVR Phase-2 has been focused on the two and three-wheeler vehicle segments considering their size in the Indian market. However, the entire population of these segments could not be covered due to data limitations. For GVR to appeal to a larger audience, these segments need to be incorporated.

   The domestic sales trends for the year 2019-20 indicate, there is a significant portion of passenger and commercial four-wheelers accounting for approximately 16% of total vehicles (Society of Indian Automobile Manufacturers, 2021). In the context of vehicular pollution, vehicle types matter more than vehicle volume. A recent study compared the air pollution levels caused by the movement of trucks as opposed to the volume of passenger vehicle traffic. The study revealed that air pollution levels dipped in the subject area despite an increase in passenger vehicle volume, when truck movement density was reduced (Wang, 2018). Hence GVR as a consumer information tool must branch out to incorporate larger vehicle segments.

6. **Automation and Advanced Analytics**: With new models being introduced by OEMs frequently and the specifications of the existing models getting revised based on real-life experience and customer feedback, it is important to automate the ingestion of necessary datasets for updated analysis as the existing piece is static in nature. Moreover, there is an inherent risk for the tool of becoming irrelevant, if there are substantial revisions in the vehicle specifications. For instance, the clustering of ICE and EVs done above is dynamic and will require constant updating based on the changes in the vehicular dataset. Also, there is a need to continuously gather novel insights and publish them on the website for enhanced understanding and awareness of customers and will ignite interest for further research across the scientific community. Thus, there is a need of deploying the entire data pipeline on cloud setup and build machine learning models quickly and deploy them using cloud APIs. This will allow for auto-incorporation of the new vehicle models in clustering analysis and will manifest key facets of those models.

Regulatory Facets

1. **Form 22 availability**: The official notification from the Ministry of Road Transport and Highways (MoRTH) specifies that this form is to be issued by the manufacturer and every consumer must be in possession of Form-22 while registering their vehicle. The form has details like brand, chassis number, engine number, emission norms (Bharat Stage- IV, VI), and emission values. The Central Motor Vehicle Rule (CMVR) 1989, rules 115 and 116, has been amended to legally support this information disclosure.

   However, while collecting data for GVR the on-ground realities were astoundingly different. Firstly, the auto dealers were reluctant to share Form-22 until a purchase was made. Second, the document, while accessible by the consumer at the time of vehicle purchase, is not available in the public domain on the lines of technical features of the vehicle. In the interest of climate change intervention, emission details of the vehicle models must be published for open access. Therefore, a formal way to source vehicle pollution data must be enabled with government intervention.

2. **Mainstreaming environmental parameters**: 'Star-Label' program provides the consumer an informed choice about energy-saving, and thereby the cost-saving potential of the marketed product. Similar to this program spearheaded by the Bureau of Energy Efficiency for electrical appliances, governments, and allied regulatory bodies must subscribe to frameworks that promote greener vehicle choices. GVR presents a system for the consumer to actively participate in green and sustainable transition. Such rating systems must be supported by government agencies to help increase consumer awareness around the consequences of their vehicle's environmental performance.

3. **Nudging for better fuel efficiency**: The government under the aegis of the Bureau of Energy Efficiency also sets corporate fuel consumption standards for four-wheeler passenger cars. These norms aim at improving the fuel efficiency of cars and at the same time lowers GHG emissions. The CAFÉ standards are fleet-wide averages that must be achieved by each automaker. Stricter CAFÉ targets can also lead to manufacturers moving to electric or strong hybrid vehicles over medium to long-term to comply with the norms. The GVR program provides the opportunity to develop dedicated Corporate Average Fuel Economy (CAFE) standards for two and three-wheelers.

In the interest of a cleaner and efficient future, it is necessary that the supply and demand needs of the transport ecosystem are nudged towards greener alternatives. Critical information asymmetries exist concerning the health and environmental damages caused by automobiles. This warrants information tools be provided to the consumer to make greener vehicle choice(s) within their financial capacity. Such a shift in demand will gradually open up avenues for automobile manufacturers to prioritize their vehicles' efficiency.

In the long run, bridging such information gaps towards cleaner alternatives can ensure that the transport sector supports a sustainable future. Information tools also function as catalysts to achieve the government's broader objective to promote e-mobility and contribute to the Sustainable Development Goals. Mainstreaming health and environmental impact as part of consumer's criteria for vehicle choice is a crucial step forward to enable sustainable transportation.

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8. Annexures

Annexure I: Summary of Technical features of International Vehicle Rating Programs

Name of the Rating	EcoScore (Belgium)	Next Green Car (UK)	ACEEE's greenercars.org (USA)	Clean Vehicle Europe (CVE)[1] (Europe)	Green Vehicle Guide (GVG) (Australia)	Rightcar (New Zealand)
Pollutant emissions	NOx, PM, CO, NMHC and SOx	Tail pipe: CO, HCs, NOx, PM10 Indirect emissions: CO, HCs, NOx, PM10, SO_2	CO, HC, NOx, PM10, Sox	NOx, PM and NMHC	None	CO, HC, NOx, PM10 (only for diesel models)
GHG emissions	CO_2, CH4, N_2O	CO_2 Indirect emissions: N_2O, CH4, CO_2	CO_2, HC, NOx, CO, CH4, N_2O	CO_2	CO_2	CO_2
Source of emissions data	Government bodies: Dutch 'Rijksdient Voor Wegverker'(RDW) and 'Dienst Inschrijvig Voertuigen' (DIV)	UK Vehicle Certification Agency + Emissions Analytics for Real Driving Emissions (RDE) and EQUA indices	Automakers report the testing results to EPA and the California Air Resources Board (CARB). EPA averages results over the lifetime of the vehicle	Data not available	Data from Australian Design Rule (ADR) 81/02, 79, 83/00 stationary noise test is submitted by manufacturers	Test data provided when the car was manufactured
Framework used	External costs Based	External costs based	External costs Based	External costs based	No external costs framework	No external costs framework
Characterisation	1. Global Warming Potential (GWP) 2. Health costs health from pollutants 3. Noise levels in dB(A)	Aggregated external impacts are valuated for each emission type.	Monetary damage costs on human health Environmental Damage Index (EDX)	Converts emissions into monetary costs w/ external costs for PM, NOx, and NMHC, ETS for CO_2, and fuel price for energy	No characterisation	No characterisation

[3] May be discontinued.

Name of the Rating	EcoScore (Belgium)	Next Green Car (UK)	ACEEE's greenercars.org (USA)	Clean Vehicle Europe (CVE)[1] (Europe)	Green Vehicle Guide (GVG) (Australia)	Rightcar (New Zealand)
Source of External Costs from Pollutant Emissions	ExternE Project: for external costs from air pollution Global warming potential based on IPCC methods.	ExternE, Emissions Analytics (This rating argues that ExternE numbers are not accurate)	Delucchi et al (1997)	ExternE, (Clean Air for Europe) CAFE, HEATCO Studies	Emissions are not converted to monetary costs	Emissions are not converted to monetary costs
Normalisation	A reference vehicle following Euro IV standards is used for normalization	The methodology 'normalises' the external costs by dividing the total external cost by a 'maximum' value	A pre-control vehicle (highly polluting vehicle) is used for normalization	No normalisation, hence no rating; Only costs incurred from damages caused by emissions are given as Operational Lifetime Costs (OLC)	None	None
Weighting	1. 40% Air quality: (20% human health + 20% ecosystems damage) 50% Climate change, 10% Noise. This results in Total Impact (TI)	50% air quality and 50% GHG	70% GHG and 30% criteria pollution	No weighting	No weighting	No weighting
Algorithm for Final Score	Rescaling of TI to Ecoscore: Ecoscore = 10*exp(- 0,00357*TI)	QCO2 (CO 2 external cost in €/km) = (TPxEC) +(FPxEC) +(VPxEC) NGC Rating (CO2) = 100 x QCO2 (external cost) ÷ QCO2 ('max' external cost)	EDX is converted into Green Score through an inequality formulae.	OLCPM= lifetime mileage (km)* PM emissions gm/km * PM Cost €/kg (Similarly, OLC is calculated for every pollutant and GHG and is added up as Total Operational Lifetime Costs)	GVG ranks vehicles by tailpipe CO_2 emissions. In cases where combined tailpipe CO_2 emissions are equal, vehicles are then ranked by urban CO_2 emissions	

Annexure II: Overall results for 2-Wheelers ICE models

S.No.	Pseudo Name	Engine cc	Declared Fuel Economy (km/l)	Total Health Damage Cost (INR/km)	Total Environmental Damage Cost (INR/ km)	Composite Damage Cost (INR/km)	Total Cost of Ownership (INR/km)	Real Cost of Ownership (INR/km)	Health Rating	Environmental Rating	Damage Score	GVR
1	ICE-B-1	97.2	62.5	0.04	0.02	0.05	3.2	3.25	1.18	0.27	1.45	4.5
2	ICE-B-2	160	48	0.04	0.024	0.06	4.62	4.68	1.64	0.38	2.02	3.5
3	ICE-B-3	200	40	0.05	0.029	0.08	5.32	5.4	1.35	0.31	1.66	4
4	ICE-B-4	200	40	0.07	0.031	0.11	5.31	5.42	2.05	0.34	2.39	3.5
5	ICE-B-5	124.7	55	0.04	0.022	0.06	3.7	3.76	2.15	0.42	2.57	3
6	ICE-B-6	113	60	0.03	0.019	0.05	3.37	3.42	1.44	0.35	1.8	4
7	ICE-B-7	97.2	65	0.02	0.017	0.04	3.07	3.11	0.79	0.24	1.04	4.5
8	ICE-B-8	113.2	55	0.03	0.02	0.05	3.51	3.56	1.52	0.38	1.91	4
9	ICE-B-9	124.7	57	0.04	0.021	0.06	3.51	3.57	2.04	0.4	2.45	3.5
10	ICE-S-1	110	45	0.04	0.025	0.06	3.7	3.76	1.84	0.48	2.32	3.5
11	ICE-S-2	124.6	45	0.06	0.028	0.08	3.93	4.01	2.8	0.52	3.32	2.5
12	ICE-S-3	124.6	45	0.04	0.025	0.06	3.89	3.95	1.87	0.48	2.35	3.5
13	ICE-S-4	110	50	0.04	0.023	0.06	3.4	3.46	1.79	0.44	2.23	3.5
14	ICE-B-10	124.73	65	0.03	0.018	0.05	3.51	3.55	1.37	0.35	1.72	4

S.No.	Pseudo Name	Engine cc	Declared Fuel Economy (km/l)	Total Health Damage Cost (INR/km)	Total Environmental Damage Cost (INR/km)	Composite Damage Cost (INR/km)	Total Cost of Ownership (INR/km)	Real Cost of Ownership (INR/km)	Health Rating	Environmental Rating	Damage Score	GVR
15	ICE-S-5	124	47.5	0.04	0.025	0.06	3.89	3.96	1.92	0.47	2.39	3.5
16	ICE-S-6	124	47.5	0.04	0.025	0.07	3.82	3.89	2.05	0.48	2.52	3
17	ICE-B-11	184.4	45	0.04	0.026	0.07	5.33	5.39	1.14	0.28	1.42	4.5
18	ICE-S-7	124	45	0.04	0.026	0.07	3.96	4.03	2.06	0.49	2.55	3
19	ICE-B-12	109.51	64.5	0.03	0.019	0.05	3.17	3.23	1.76	0.36	2.13	3.5
20	ICE-B-13	162.7	50	0.03	0.022	0.05	4.35	4.41	1.25	0.35	1.6	4
21	ICE-B-14	162.71	48	0.04	0.024	0.06	4.72	4.78	1.46	0.37	1.84	4
22	ICE-B-15	109.51	60	0.03	0.02	0.05	3.5	3.55	1.56	0.38	1.94	4
23	ICE-B-16	110	70	0.02	0.017	0.04	2.79	2.83	1.26	0.32	1.58	4
24	ICE-B-17	110	70	0.02	0.017	0.04	3.04	3.08	1.15	0.32	1.47	4.5
25	ICE-B-18	160	45	0.06	0.028	0.09	4.69	4.78	2.42	0.44	2.86	3
26	ICE-B-19	250	33	0.06	0.035	0.09	6.99	7.09	1.47	0.36	1.83	4
27	ICE-B-20	125	51	0.04	0.023	0.06	3.78	3.84	1.48	0.37	1.85	4
28	ICE-B-21	160	42	0.07	0.03	0.1	4.9	5	2.71	0.47	3.18	2.5
29	ICE-B-22	150	50	0.04	0.024	0.06	4.31	4.37	1.62	0.38	2	3.5

Annexure III: Overall results for 2-wheelers EV models

S.no.	Pseudo Name	Battery Capacity (kWh)	Fuel Economy (km/kWh)	Total Health Damage Cost (INR/km)	Total Environmental Damage Cost (INR/km)	Composite Damage Cost (INR/km)	Total Cost of Ownership (INR/km)	Real Cost of Ownership (INR/km)	Health Rating	Environmental Rating	Damage Score	Green Vehicle Rating
1	EVS-1	1.15	35.0	0.022	0.004	0.03	0.95	0.97	0.74	0.49	1.23	4.5
2	EVS-2	1.15	33.5	0.023	0.005	0.03	0.87	0.90	0.77	0.51	1.29	4.5
3	EVS-3	1.8	34.0	0.022	0.004	0.03	1.01	1.03	0.98	0.66	1.64	4
4	EVS-4	1.8	29.2	0.026	0.005	0.03	0.83	0.86	1.15	0.77	1.91	4
5	EVS-5	2.7	27.2	0.028	0.006	0.03	1.57	1.60	0.68	0.45	1.13	4.5
6	EVS-6	2.9	28.2	0.027	0.005	0.03	1.52	1.55	0.65	0.44	1.09	4.5
7	EVS-7	2.88	20.0	0.038	0.008	0.05	1.28	1.33	0.93	0.62	1.54	4
8	EVS-8	1.2	35.0	0.022	0.004	0.03	0.78	0.81	0.74	0.49	1.23	4.5
9	EVS-9	1.2	35.0	0.022	0.004	0.03	0.79	0.81	0.74	0.49	1.23	4.5
10	EVS-10	1.53	38.9	0.019	0.004	0.02	0.94	0.97	0.86	0.57	1.44	4.5
11	EVS-11	1.53	55.8	0.014	0.003	0.02	0.86	0.88	0.60	0.40	1.00	5
12	EVS-12	1.872	29.9	0.025	0.005	0.03	0.76	0.79	1.12	0.75	1.87	4
13	EVS-13	1.536	22.8	0.033	0.007	0.04	1.10	1.14	1.13	0.76	1.89	4
14	EVS-14	2.68	26.1	0.029	0.006	0.03	0.61	0.64	0.71	0.47	1.18	4.5
15	EVS-15	1.34	26.1	0.029	0.006	0.03	0.94	0.98	0.99	0.66	1.65	4
16	EVS-16	0.96	36.5	0.021	0.004	0.02	0.76	0.79	0.72	0.48	1.20	4.5
17	EVS-17	1.536	37.4	0.020	0.004	0.02	0.82	0.85	0.90	0.60	1.49	4.5

S.no.	Pseudo Name	Battery Capacity (kWh)	Fuel Economy (km/kWh)	Total Health Damage Cost (INR/km)	Total Environmental Damage Cost (INR/km)	Composite Damage Cost (INR/km)	Total Cost of Ownership (INR/km)	Real Cost of Ownership (INR/km)	Health Rating	Environmental Rating	Damage Score	Green Vehicle Rating
18	EVS-18	0.96	36.5	0.021	0.004	0.02	0.76	0.79	0.72	0.48	1.20	4.5
19	EVS-19	0.96	43.8	0.017	0.003	0.02	0.71	0.73	0.60	0.40	1.00	5
20	EVS-20	0.96	43.8	0.017	0.003	0.02	0.75	0.77	0.60	0.40	1.00	5
21	EVS-21	1.74	33.8	0.022	0.005	0.03	1.17	1.20	0.99	0.66	1.65	4
22	EVS-22	3.3	29.5	0.026	0.005	0.03	1.44	1.47	0.90	0.60	1.49	4.5
23	EVS-23	2	30.8	0.025	0.005	0.03	1.08	1.11	0.60	0.40	1.00	5
24	EVS-24	1.25	33.6	0.023	0.005	0.03	1.10	1.13	0.77	0.51	1.28	4.5
25	EVS-25	2.25	23.3	0.032	0.007	0.04	1.54	1.58	0.79	0.53	1.32	4.5
26	EVS-26	1.56	43.8	0.017	0.003	0.02	0.79	0.81	0.77	0.51	1.28	4.5
27	EVS-27	1.92	35.5	0.021	0.004	0.03	0.56	0.58	0.94	0.63	1.57	4
28	EVS-28	1.56	39.3	0.019	0.004	0.02	0.79	0.81	0.85	0.57	1.42	4.5
29	EVS-29	1.92	31.9	0.024	0.005	0.03	0.57	0.60	1.05	0.70	1.75	4
30	EVS-30	1.56	43.8	0.017	0.003	0.02	0.85	0.87	0.77	0.51	1.28	4.5
31	EVS-31	1.92	35.5	0.021	0.004	0.03	0.85	0.88	0.94	0.63	1.57	4
32	EVS-32	1.56	43.8	0.017	0.003	0.02	0.82	0.84	0.77	0.51	1.28	4.5
33	EVS-33	1.92	35.5	0.021	0.004	0.03	0.58	0.60	0.94	0.63	1.57	4

Annexure IV: Clustering of ICE Models

Pseudo Name	ICE-B-1	ICE-B-2	ICE-B-3	ICE-B-4	ICE-B-5	ICE-B-6	ICE-B-7	ICE-B-8	ICE-B-9	ICE-S-1	ICE-S-2	ICE-S-3	ICE-S-4	ICE-B-10	ICE-S-5
Cluster	2	2	1	1	2	2	3	2	2	2	1	2	2	3	2

Pseudo Name	ICE-S-6	ICE-B-11	ICE-S-7	ICE-B-12	ICE-B-13	ICE-B-14	ICE-B-15	ICE-B-16	ICE-B-17	ICE-B-18	ICE-B-19	ICE-B-20	ICE-B-21	ICE-B-22
Cluster	2	1	2	3	2	2	2	3	3	1	1	2	1	2

Annexure V:Clustering of EV Models

Pseudo Name	EVS-1	EVS-2	EVS-3	EVS-4	EVS-5	EVS-6	EVS-7	EVS-8	EVS-9	EVS-10	EVS-11	EVS-12	EVS-13	EVS-14	EVS-15	EVS-16	EVS-17
Cluster	1	1	2	2	3	3	2	1	1	1	1	2	2	1	2	1	1

Pseudo Name	EVS-18	EVS-19	EVS-20	EVS-21	EVS-22	EVS-23	EVS-24	EVS-25	EVS-26	EVS-27	EVS-28	EVS-29	EVS-30	EVS-31	EVS-32	EVS-33
Cluster	1	1	1	2	3	1	1	3	1	2	1	2	1	2	1	2

Annexure VI: Cost calculation assumptions for 2-wheelers ICE models and EV models

Cost assumptions for ICE models

1. Ratings are adjusted by 30% to account for discrepancy between test values and real driving conditions
2. Life of the vehicle assumed to be 10 years
3. Tyre replacement will happen after 5 years if driving 1000 km in a month. As the life of the vehicle assumed 10 years, it doesn't make economical sense for consumers to replace the tyres in the 10th year. So assumed one time replacement.
4. Depreciation assumed to be constant after year 3
5. Service cost same for all the years
6. Geometric mean of low and high marginal damage cost is considered instead of airthmetic mean
7. Assuming no extended warranty cost, handling or logistics prices charged
8. Cut-off date for regulatory changes as Feb'2020
9. Reference vehicle fuel economy assumed to be 30% more than the maximum achieved by vehicle in that class
10. Equal weightage to both health and environmental rating

Cost assumptions for EV models

1. Ratings are based on the level of standards to which vehicle is certified until more data becomes available
2. Rate of decline in grid emission factor assumed based on the value predicted by CEA for 2029
3. No decline in the emission value is assumed over the years
4. We are considering only central susbsidy as it will be difficult to account for state subsidy. After including the state subsidy, TCO will decline further.
5. No road tax or registration charges for Evs
6. Tax collected at source – all the vehicles sold at an ex-showroom price of more than INR 1 million ($14,200) are eligible for a rebate of 1 per cent of that price.
7. Fuel Efficiency of the vehicle is derated to consider the thermal losses, discrepancy in the real and test values
8. GST rates for EVs lower than ICE but already included in their ex-showrooom price so not showing separate treatment
9. Salvage value is assumed to be 50% of the value

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