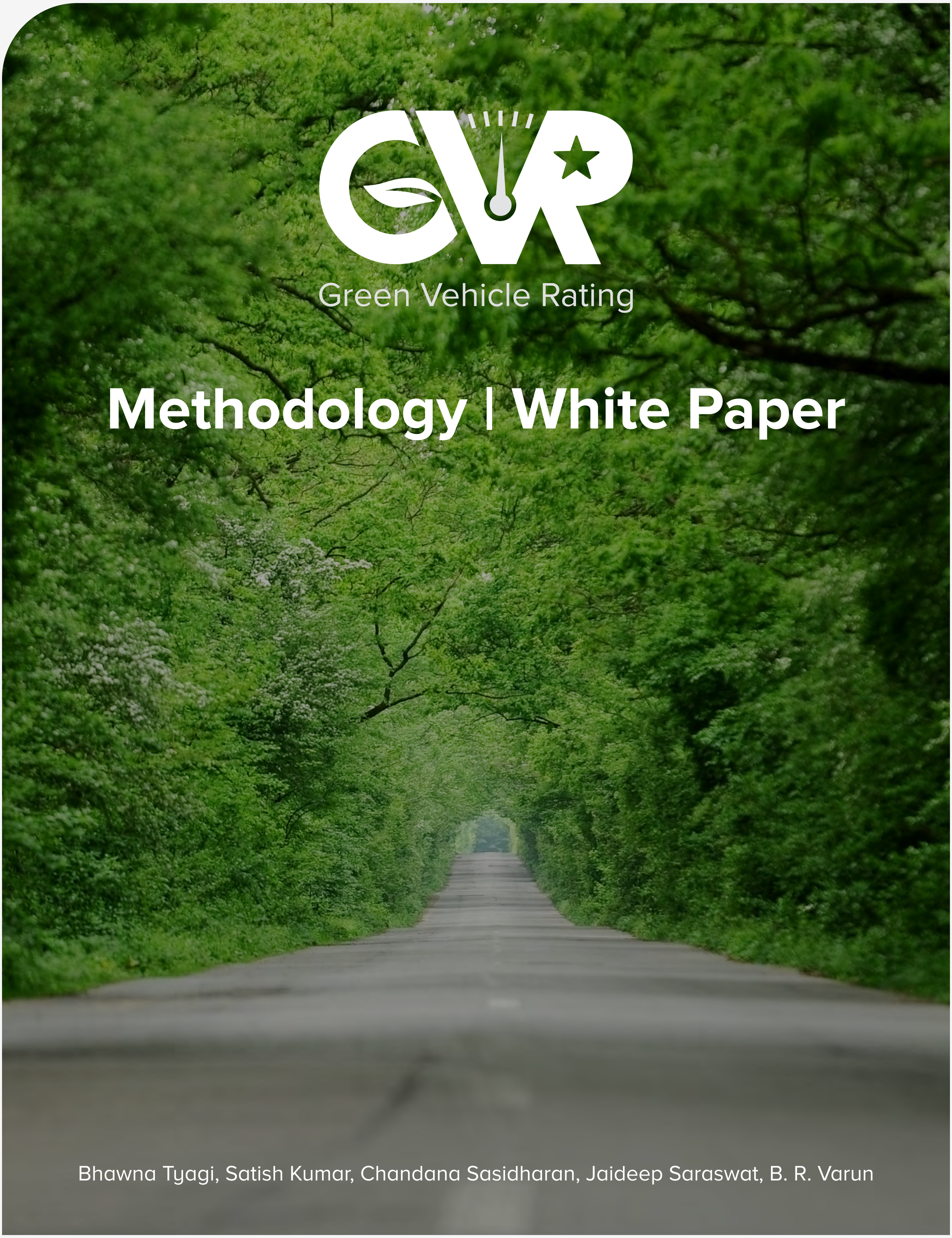


Green Vehicle Rating

Methodology | White Paper

Bhawna Tyagi, Satish Kumar, Chandana Sasidharan, Jaideep Saraswat, B. R. Varun

Alliance for an™ Energy Efficient Economy

SHAKTI SUSTAINABLE ENERGY FOUNDATION

Suggested citation:

Tyagi, B., Kumar, S., Sasidharan, C., Saraswat, J., & Varun, B. R. (2021). Whitepaper on Green Vehicle Rating Methodology. New Delhi: Alliance for an Energy Efficient Economy.

About Alliance for an Energy Efficient Economy:

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

About Shakti Sustainable Energy Foundation:

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.

Contact:

Chandana Sasidharan
Principal Research Associate
Power Utility & Electric Mobility
Alliance for an Energy Efficient Economy (AEEE)
New Delhi
E: info-puem@aeee.in

Acknowledgements:

The authors would like to acknowledge Anumita Roy, Centre for Science and Environment, Anup Bandivadekar, International Council for Clean Transport, Karthik Ganesan, Council on Energy, Environment and Water, Dr. Sarath K. Guttikunda, Urban Emissions, and Vivek Chandran, Shakti Sustainable Energy Foundation for their inputs on the methodology.

Table of Contents

List of Tables

List of Figures

1. Introduction

AEEE has pioneered a programme called the Green Vehicle Rating (GVR), which is India's only vehicle rating system based on vehicles' environmental performance. GVR for two- and three-wheelers is designed to create evidence-based awareness in consumers and shift their demand towards greener variants that rely on low emissions technology and high fuel economy. GVR allows consumers to identify the cleanest and most economically sensible vehicle models from an available pool, gives consumers web-based access to easy-to-understand information – in monetary terms – to inform their purchase decisions, and enables them to see the costs and benefits of owning greener 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

Although petrol and diesel-run vehicles constitute the bulk of the on-road fleet in India, electric vehicles (EVs) are gradually gaining momentum in the automotive sector. Furthermore, there is growing support from policymakers for e-mobility. EVs have zero tailpipe emissions, but they can still result in greenhouse gas (GHG) and criteria pollutant emissions, as they are currently drawing electricity from fossil fuel (coal-fired, in the case of India) dominated power mix. In the case of an EV, there is no fuel combustion in the vehicle tank; rather, the emissions occur at the power plant level, i.e. the power plants can be regarded as the counterparts of vehicle petrol tanks of the internal combustion engine (ICE)-based models. In other words, the emissions shift from the tailpipe to power plants in the case of EVs.

Therefore, it is important to rate and compare the EV models alongside ICE-based models under the GVR programme, even more so when there is a heated ongoing debate regarding whether to accept EVs as cleaner than ICE vehicles.

The first version of GVR was launched in 2018 (Kumar, 2018) and served as a consumer information tool that identified high- to low-performing vehicle models in terms of the negative impacts of GHG emissions and criteria pollutants released from the tailpipes. The first phase of GVR only covered Bharat Stage (BS)-IV compliant ICE vehicles. The approach adopted to estimate the ratings was focused on tank-to-wheel emissions.

However, now, in the second phase, the focus is on BS-VI complaint ICE models and electric variants of both two-wheeler and three-wheelers. Therefore, to rate EV models alongside ICE-models, we calculate the upstream emissions (limited to fuel production and distribution) and tailpipe emissions (GHGs and air pollutants) due to fossil fuel combustion and measure plant-to-wheel emissions. GVR ratings of the models can be accessed online at https://green-vehicle-rating.aeee.in/.

This paper presents the approach, assumptions, and analytical process used to calculate the ratings in GVR Phase 2, launched in 2021 for both ICE vehicles and EVs.

2. Green Vehicle Rating Methodology

Approach to calculating GVR

Vehicles generate negative externalities, from the production stage up to the vehicle disposal. There are two common 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 the damage cost focuses on the repercussions due to pollution (Vaidyanathan, Slowik, & Junga, 2016). The GVR uses a 'damage cost' methodology to estimate the costs of the negative environmental and health-related impacts of criteria pollutants and GHGs. These costs are expressed in Indian rupees (INR, or ₹) per kilometre (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 moves 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 ₹/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 1. 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.

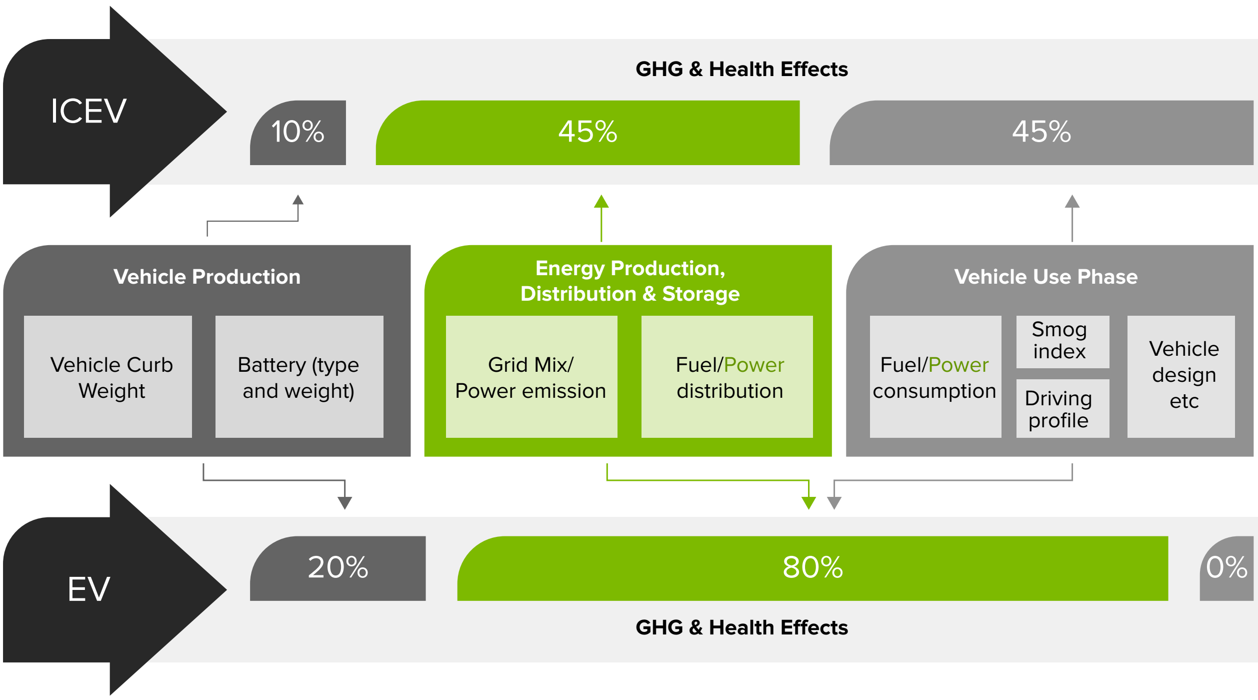


Figure 1: Environmental and health effects of ICE and EVs

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

Key steps

To calculate the different vehicle models' GVR ratings, the study has adopted a five-step approach, as shown in Figure 2. 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:

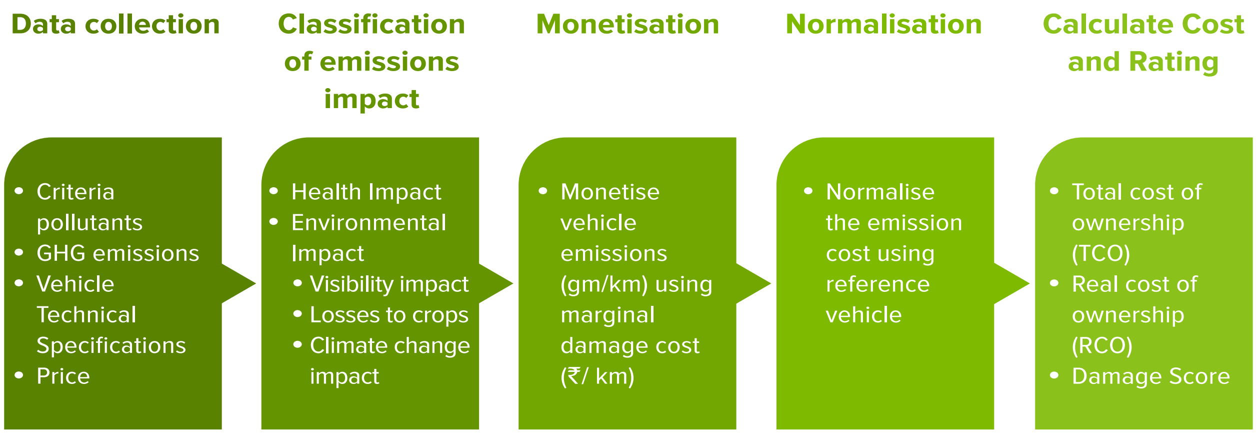


Figure 2: Key GVR calculation steps

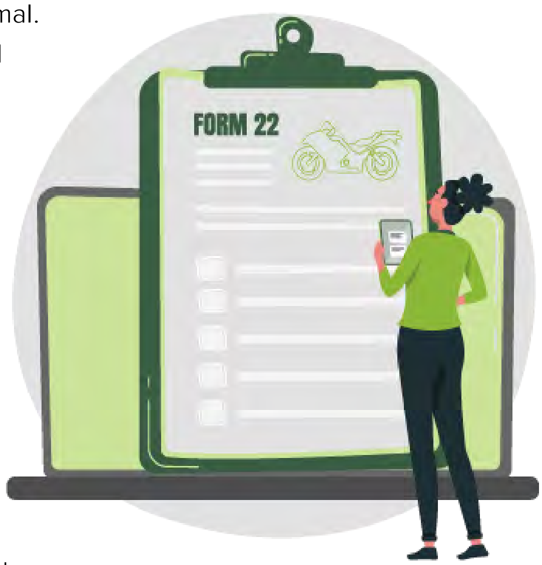
Step 1: Data collection

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 carbon monoxide (CO), nitrous oxides (NOx), hydrocarbon (HC), and particulate matter (PM)—emitted from tailpipes can be sourced directly from Form 22, a document issued by automakers 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 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-authorised 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. We started by reaching out to automotive dealers to get Form 22. The dealers were generally either reluctant to disclose this information or only willing to share it if we made 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 carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O). Carbon emission factors are estimated using the formula specified in Table 1. 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).

Table 1: 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 Molecular Mass Ratio	Fuel Density (kg/L)**	Carbon Dioxide Emission Factor (g/L)
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 the Intergovernmental Panel on Climate Change (IPCC)

** As per BS-IV fuel specifications

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 2.

Table 2: ICE vehicle data type, parameters, and sources

Data Type	Parameter	Source
Tailpipe Emission Data	Criteria Pollutants (CO, NOx, HC, PM)	Form 22
	Carbon Emissions (g/km)	Method II: IPCC, MoPNG
	CH_4, N_2O, and SO_2	(Next Green Car, 2016); (TransportPolicy.net, n.d.)
	Global Warming Potential (GWP)	(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 (L))	Third-party dealer websites
	Costs (such as depreciation, financing, tyre replacement, insurance, etc.)	Third-party dealer websites (such as droom)

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 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 3.

Table 3: EV data type, parameters, and sources

Data Type	Parameter	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)
	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/L)	Estimated using battery capacity and range
	Costs (such as depreciation, financing, 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 are 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. 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 criteria 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 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 environment.

Public health impacts: Prolonged inhalation of air pollutants (NOx, CO, HC, and PM 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.

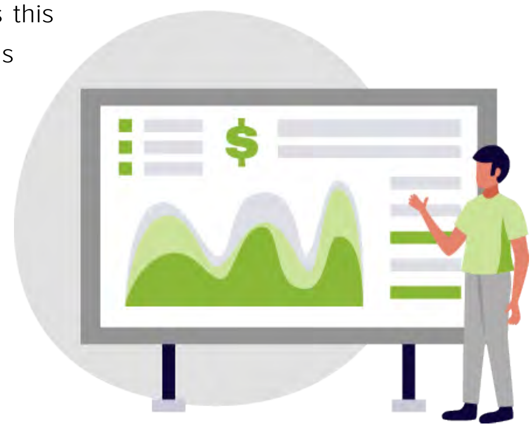
Environmental impacts: These impacts include adverse effects from global warming due to GHGs (CO_2, CH_4, and N_2O). Human activities dependent on the burning of fossil fuels produce CO_2, which is the most significant heat-trapping gas that accelerates the natural GHG effect. This leads to excessive increases in temperatures and subsequent environment damage. Methane, another heat-trapping gas, is the second most significant contributor to climate change. In 2018, the transport sector accounted for nearly 13.2% of carbon emissions in India (IEA, 2021). 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 volatile organic compounds (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 3.

Figure 3: GHG and air pollutant impacts covered in GVR

Step 3: Monetisation

For consumers to appreciate and purchase clean, efficient vehicles, they need straightforward 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, 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 the UK's Next Green Car rating systems. Similarly, the American Council for an Energy-Efficient Economy (ACEEE) GreenerCars initiative used the social cost estimation by McDeluchhi and the Greenhouse gases, Regulated Emissions, and Energy use in Transportation (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 were 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 4:

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.

[1] The Social Cost of Carbon is the marginal cost of the impacts caused by emitting one extra tonne of greenhouse gas at any point in time, inclusive of non-market impacts on the environment and human health.

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.

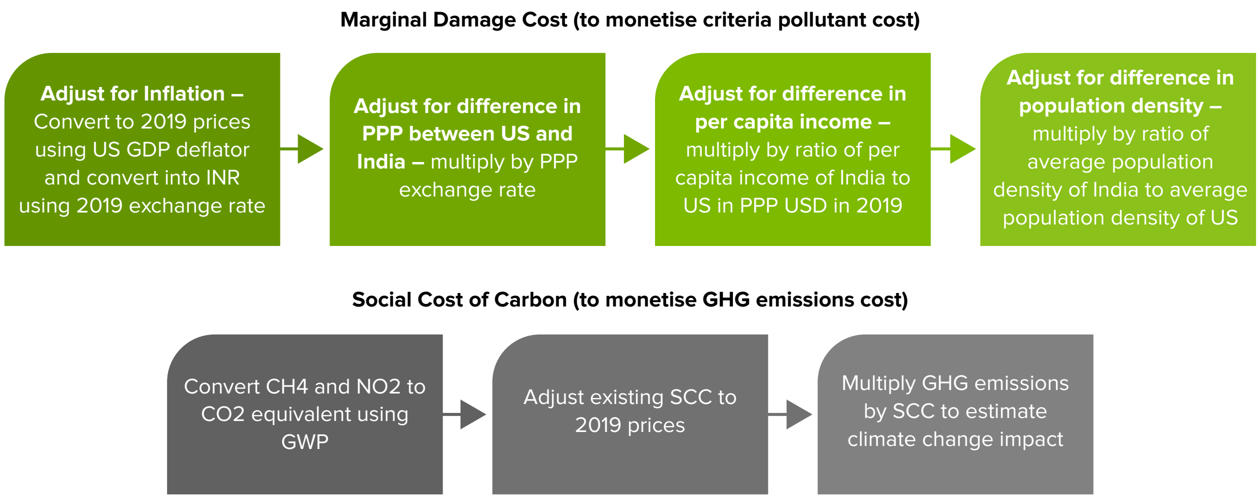


Figure 4: Key GVR rating calculation steps

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.

	Marginal Visibility Costs			Marginal Health Costs			Marginal Crop Loss Costs		
Pollutant	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 have been reduced by a factor of 10 due to the difference 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 health 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 vehicle models considered were compliant with BS-IV emission standard. In order to perform the vehicle ranking process an ideal reference vehicle with superior emission standards was necessary. Thus, a BS-VI emission standard vehicle was set as the reference model. 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 vehicles 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. Unlike GVR Phase I, the vehicles considered in Phase II do not have an existing superior emission standard notified by the central government. Hence, 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 calculation

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. The emissions calculation for EVs is discussed in Box 1.

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

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

Box 1: EV emissions calculation

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 CO2 equivalent and then multiplied by the SCC, as shown in Box 2.

- 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) * SCC (₹/g)

Note:
**Emissions include GHGs (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. 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 abovementioned 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 + Crop Loss Cost
  - 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
  - Crop Loss Cost (₹/km) = Cost of HC + Cost of NO_x
- Composite Damage Cost (₹/km) = Health Cost + Environmental Cost
- Total Cost of Ownership (₹/km) = Vehicle Cost + Interest Rate + Fuel Cost + Service Charges + Tyre Replacement 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

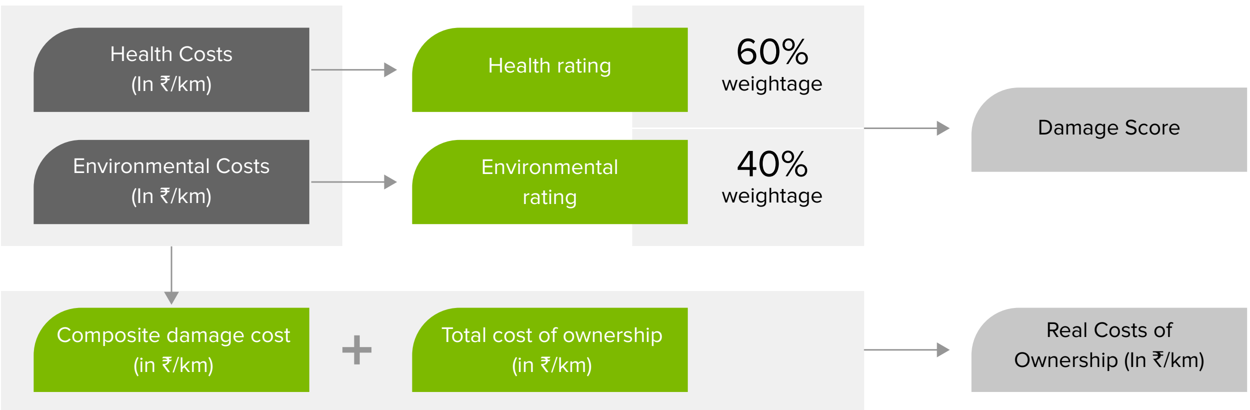


Figure 5: Summarises the relationships between the different costs and scores mentioned above

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.

References

bikewale. (n.d.). Retrieved from https://www.bikewale.com/.

BNEF. (2020, December 16). Battery Pack Prices Cited Below $100/kWh for the First Time in 2020, While Market Average Sits at $137/kWh.

CEA. (2020). *Monthly Reports: Executive Summary*. Central Electricity Authority.

CEA. (2020). *REPORT ON OPTIMAL GENERATION CAPACITY MIX For 2029-30*. Central Electricity Authority.

Central Motor Vehicle Rules. (1989). MoRTH.

EPA. (n.d.). *Basic Information about Carbon Monoxide (CO) Outdoor Air Pollution*. Retrieved from https://www.epa.gov/co-pollution/basic-information-about-carbon-monoxide-co-outdoor-air-pollution#What%20is%20

Guttikunda, S. K., & Jawahar, P. (2018). Evaluation of Particulate Pollution and Health Impacts from Planned Expansion of Coal-Fired Thermal Power Plants in India Using WRF-CAMx Modeling System. *Aerosol and Air Quality Research*, 3187–3201.

ICAT. (2017). *Development Test Report on Laboratory and On Road emissions Testing of In-use Passenger Vehicle In India*. International Center for Automotive Technology.

Innovation Center for Energy and Transportation. (2015). *China Green Car Methodology Upgrade Report*.

International Energy Agency. 2021. *Data browser*.

IPCC. (2018). *Atmospheric Chemistry and Greenhouse Gases*. IPCC.

Kumar, S.Y. (2018). *Green Vehicle Rating for 2 and 3 Wheelers in India*. New Delhi: Alliance for an Energy Efficient Economy .

MoHI&PE. (2019). *Notification* . Ministry of Heavy Industry and Public Enterprises.

Next Green Car. (2016). *NGC Rating Methodology*. Next Green Car Limited.

Patil, M., & Ghate, A. (July 2020). THE ROLE OF INCENTIVES IN REDUCING THE TOTAL COST OF OWNERSHIP OF ELECTRIC VEHICLES IN DELHI, INDIA. *Forum*, 15-18.

Ricke, K., Drouet, L., Caldeira, K., & Tavoni, M. (2018). Country level social cost of carbon. *Nature Climate Change*.

Sengupta, R., & Mandal, S. (2002). *Health Damage Cost of Automotive Air Pollution: Cost BenefitAnalysis of Fuel Quality Upgradation for Indian Cities*. eSocialSciences.

TransportPolicy.net. (n.d.). *INDIA: FUELS: DIESEL AND GASOLINE*. Retrieved from Transport Policy.net.

Vaidyanathan, S., Slowik, P., & Junga, E. (2016). *Rating the Environmental Impacts of Motor Vehicles: ACEEE's greenercars.org Methodology*. ACEEE.

WHO. (2003). *Climate Change and Human Health - Risks and Responses*. World Health Organisation.

WHO. (2018, June 1). *Noncommunicable diseases*. Retrieved from https://www.who.int/news-room/fact-sheets/detail/noncommunicable-diseases.

Alliance for an Energy Efficient Economy™

Our Office: 37 Link Road, Ground Floor,
Lajpat Nagar III,
New Delhi, 110 024

E-mail: info@aeee.in

Web: www.aeee.in

Phone: +91-11-4123 5600