A consumer information system to grow the share of clean and efficient vehicles

GREEN VEHICLE RATING FOR 2 AND 3 WHEELERS IN INDIA

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AN INITIATIVE BY

Alliance for an Energy Efficient Economy

An initiative supported by

SHAKTI SUSTAINABLE ENERGY FOUNDATION

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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.

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Transport sector, one of the highest emitters of GHGs in India

312.3 million tCO_2e per annum

Economic cost of air pollution in India

USD 560 billion

(PPP adjusted)

1.4 million

deaths from air pollution in India in 2013

One-third of Indian households own a two-wheeler

Executive Summary

One of the most effective ways to nudge the transport sector towards an efficient and cleaner future is to influence consumer purchase in favour of 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 costs and adopt cleaner variants, resulting in an increased demand and encouraging automakers to alter technologies. It may also boost the implementation and effectiveness of government efforts on saving fuel use and emissions in vehicles.

Additionally, India's road transport and energy landscape is unique: two and three wheeler fleet, combined, has registered an impressive growth of 7.76% CAGR over the period 2012-13 to 2017-18, more than the overall rate of increase in vehicle sales in India. Two wheelers alone consume 61% of petrol sales in India. In future as well, this trend is envisaged to continue rising, owing to growing population, shortage of reliable public transport having last mile connectivity and the need for a budget friendly transportation mode. Despite the massive share of two and three wheelers in India's vehicle fleet and oil resources, there is an untapped opportunity to bring a bottom-up shift in consumer purchase behaviour and grow the share of clean and efficient two and three wheelers in India.

A fuel economy labelling program for passenger cars is underway by the Bureau of Energy Efficiency (BEE) of the Ministry of Power. However, it focuses on passenger cars and their fuel economy and cost saving potential. No other consumer information program exists in India to account and disseminate information about the external costs of vehicular fuel use and criteria pollution.

Disclosure of vehicle pollutant levels in Form 22: A welcome first step in the right direction

Since April 2017, Ministry of Road Transport and Highways (MoRTH) requires mandatory disclosure of pollution levels (NOx, CO, HC, PM (for diesel vehicle only)) on the road-worthiness certificate (known as 'Form 22') by auto makers for consumer information while purchasing vehicles. The Central Motor Vehicle Rule (CMVR) 1989, rule 115 and 116, has been amended to legally support this information disclosure. No doubt, this is a welcome and timely move for symmetric distribution of pollutant profile of vehicle. However, there is a lack of awareness on the availability and benefits of Form 22 amongst vehicle buyers, who are the ultimate beneficiaries of Form 22. Secondly, although the emissions information is provided on Form 22, the data is not sufficiently straightforward for them to understand the 'severity of risks'[i] from exposure to pollutants and how to account for these in their purchase decisions.

Green Vehicle Rating (GVR): Reshaping consumer knowledge on environmental performance of vehicles

As a first-time effort in India, Green Vehicle Rating (GVR) 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 greenhouse gases and criteria pollutants released from tail pipes of top selling models. It is meant to inform the choices consumers make while purchasing vehicles. Along with a comparative analysis of models, the GVR shows the external costs of energy-related pollution impacts from vehicle exhausts - both GHGs and air pollutants. By making this information available to consumers, the goal is to reshape their knowledge on what are the real costs of owning a vehicle, beyond retail price-tags and self-reported mileage data supplied by auto dealers, which are commonly used as performance indicators during vehicle purchase in India. Form 22 is used as the source for pollution data and self-reported fuel efficiency figures are used to estimate GHGs. Damages to human health, climate change, visibility, and crop productivity from vehicular emissions are evaluated for every model in the market.

In its current phase, GVR evaluates the tail pipe emissions of twenty 2-wheeler models, and two 3-wheeler models. This pool includes products from Bajaj, Hero Motors, TVS, Honda, Suzuki, and Eicher. All the models currently follow Bharat Stage IV emissions norms.

Insights from international vehicle rating instruments

An analysis of vehicle rating programs in other major vehicle markets including, ACEEE's Greenercars methodology in the US, UK's Next Green Car (NGC), Belgium's ecoscore.be, Clean Vehicle Europe (CVE), Australia's Green Vehicle Guide (GVG), and New Zealand's Next Right Car, was conducted to help develop the method rating used in GVR. Each of these rating programs compared for their governance, regional scope, format of communicating the results to users, types of vehicles considered, and fuels, analytical frameworks for calculating the environmental performance of the vehicle, types and sources of data and cost factors pertinent to region, types of impacts of vehicles were examined.

Method of Rating Vehicles: Evaluating the economics of vehicular emissions

The GVR methodology comprises five steps, devised from research on international rating instruments and pertinent literature. These are:

1. ***Data survey and inventory creation:*** Data on tail pipe emission levels, air pollutants (CO, HC, NOx, PM) and greenhouse gases (CO_2, CH_4), for 22 vehicle models was collected. Mass of air pollutants was type approval data reported by auto manufacturers on Form 22, and mileage data reported by auto dealers was used for estimating mass of GHGs after using an adjustment factor.
2. ***Classifying impacts:*** GVR studies two classes of negative impacts: on human health and on environment (sub categorised into: climate change, visibility, and crop damages), from vehicle air pollution and carbon emissions.
3. ***Characterising impacts in monetary terms:*** A damage cost method is used, in which the marginal cost of mitigating damage from the release of one unit of an air pollutant and a GHG is aggregated to find the total costs of damages produced, also known as the external costs. Health damage costs and environmental damage costs per vehicle are calculated in ₹/km terms.
4. ***Normalisation:*** A reference vehicle, an ideal vehicle adhering to stringent emissions and fuel consumption norms, is used for normalisation. Health and environmental costs from other vehicles are rated against that of the reference vehicle, which produces a Damage Score, a dimensionless value. This score is used to rank vehicles for comparison.
5. ***Weighting:*** In the Damage Score, health costs are given 60% and environmental costs are given 40% weightage. This is owing to comparatively larger local air pollution damages from 2 and 3 wheelers in comparison to GHG effects.

Dissemination and presentation of rating results

Along with this report, the final results are publicised through a dedicated web-portal on GVR. The portal also allows consumers and other stakeholders to see the method, data and assumptions used to rate vehicles. The final vehicle ranking is based on the Damage Score. Additionally, for each vehicle, the health and environmental damages are listed as Composite Damage Costs (CDC) per km. To expand current understanding of cost of owning a vehicle, CDC is added to commonly known Total Costs of Ownership (TCO, which includes upfront costs, finance, fuel, depreciation and maintenance) to sensitise the consumer about the 'Real Cost of Ownership' for each vehicle. Currently, the ranking is for models manufactured in 2017. With improvement in engine technologies, fuel quality and transition to more stringent emissions norms, ranking for the coming year will likely change. Reference vehicle parameters will also be upgraded to allow for comparison between ranking of two years.

Observation and recommendations

An information strategy for controlling vehicle emissions and influencing consumer purchase behaviour is urgently needed in India. A comprehensive set of future areas of work and policy level recommendations that would complement the goals are highlighted below based on the learnings from GVR program.

- As GVR reveals the "cost" of the impact of use of different models of two and three wheelers on human health and the environment in the country and ranks the models according to their damage scores, the policymakers can leverage these insights to introduce a "feebate" system based on the "polluter pays" principle. In such a system, higher taxes are imposed on more polluting vehicle models and the revenue collected can be used to provide incentives to cleaner technologies and fund R&D activities. On similar line, the concerned authority may consider waiving the registration fee for greener variants of vehicles.

- GVR program can be leveraged by the concerned authority to introduce a Star labelling program for two and three wheelers based on the pollutant emissions profile and fuel economy of the vehicle models. Already a successful Standards & Labeling Program for certain appliances is effective in the country since year 2006, administered by BEE.

- There are suggestions from experts that the GVR program can be extended to develop a dedicated Corporate Average Fuel Economy (CAFE) standards for two and three wheelers. Currently, BEE (Bureau of Energy Efficiency) has set CAFE standard for passenger cars. Hence, similar standard can be stipulated for two and three wheelers.

Moreover, the aforesaid interventions should be complemented by specific actions such as more aggressive campaign to raise consumer awareness about Form 22, mandating the reporting of particulate emissions on Form 22 across fuel types, real driving emission testing for more accurate data on pollution levels, etc.

CHAPTER 1

Background

Putting brakes on oil demand and emissions in India's road transport

Road transport continues to be an oil guzzler in India. As per the latest government statistics, oil consumption in road transport accounts about 57% of total energy consumption (~ 45,638.39 ktoe) in transport sector[ii]. As the Indian economy is rapidly growing leading to increase in vehicle share among the population, the demand for oil in transport sector is expected to register more than 2- fold jump by 2032[iii].

No surprise, transport sector is one of the highest emitters of GHGs in India, with estimated emissions to the tune of about 312.3 million tCO_{2e} per annum[iv]. Vehicular emissions of particulate matters (PM2.5) and polluting gases such as NOx, SOx, CO, HC, etc. are also a major concern in view of the deteriorating air quality in cities. According to the World Health Organization (WHO), 14 of the 20 most polluted cities (in terms of PM2.5 concentration) are reportedly in India. The GHG and polluting gas emissions have significant external costs as indicated in Figure 1.1.

As per the World Bank study titled "Environmental Costs of Fossil Fuels", "the environmental costs of fuel use in

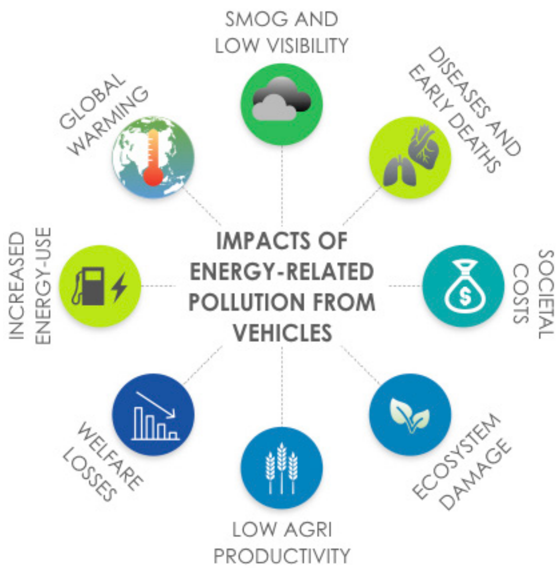


Figure 1.1: Impacts of vehicular fuel consumption and emissions

large developing country cities can be so high that marginal damage costs are comparable to or, for some fuel uses, may exceed both producer and retail product prices"[v].

Useful insights into the magnitude of the impact of pollution are also shed by The Lancet Commission on pollution and health, which has reported that pollution-related diseases are responsible for an estimated 9 million premature deaths in 2015 *i.e.* 16% of all deaths worldwide[vi]. About 92% of these deaths occur in low-income and middle-income countries. The cost of such losses to the economy is substantial. For example, welfare losses due to ambient PM2.5 pollution in South Asia are reportedly equivalent of 3.1% of the regional gross domestic product (GDP) in 2013[vii] and the trend has been alarmingly ascending as shown in Figure 1.2.

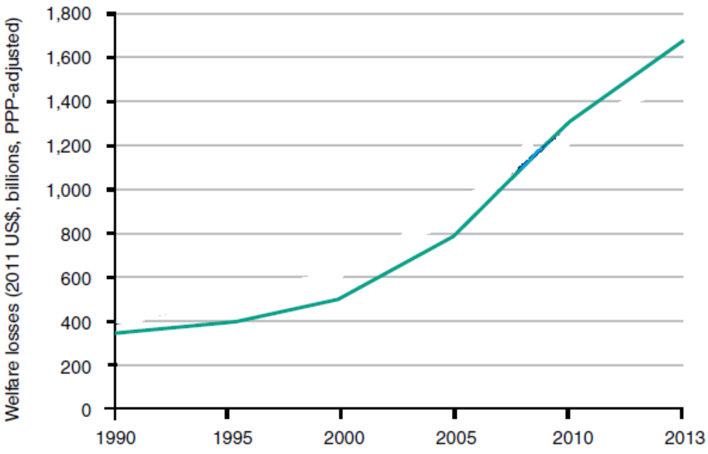


Figure 1.2: Welfare losses from ambient PM2.5 pollution in low- and middle-income countries, 1990–2013.

Source: World Bank and IHME

It is to be borne in mind that the impact and its cost cascades through the consumers, markets and the government. It is high time that necessary interventions are adopted to arrest the vehicular fuel consumption and emissions. Not to mention urgent mitigation actions would help India turn the corner in achieving the Sustainable Development Goals (SDGs), particularly SDG3: Good Health and Well-Being, SDG11: Sustainable Cities and Communities, SDG12: Responsible Consumption and Production, and SDG13: Climate Action. Moreover, it holds significance from the point of view of realizing India's Nationally Determined Contribution (NDC) – to reduce the emissions intensity of its GDP by 33% to 35% by 2030 from 2005 level.

Public information to influence vehicle choice of consumers

Although there is no single silver bullet in this regard, one of the most effective ways to nudge the transport sector towards an efficient and cleaner future is to influence consumer purchase in favour of more fuel efficient and less polluting vehicle models. In theory, this will help gradually increase the demand for greener variants of vehicles and side-line the polluting ones leading to higher share of cleaner vehicles in the market. Bringing a change in consumer behaviour starts with reliable and explicit information - on impacts of pollutants and CO_2 emissions - as they purchase vehicles. Because of the lack of information, most of the consumers remain short-sighted and tend to rely only on retail price-tags of vehicle models and self reported mileage data supplied by auto dealers while making the purchase decisions. It is critical to provide consumers reliable and comprehensive information about the overall performance of vehicle models – their fuel efficiencies and emissions (GHGs and pollutants) potential – so that the consumers can take informed decisions while choosing the vehicle models. It is also important, how the information is conveyed to the consumers so that the latter can easily appreciate and appropriately act on their own.

Current initiatives in India

A fuel economy labelling program for passenger cars is underway by the Bureau of Energy Efficiency (BEE) of the Ministry of Power. No other consumer program exists in India to account and disseminate information about the external costs of vehicular fuel use and criteria pollution.

Importance of targeting 2-wheeler and 3-wheeler segments

Two wheelers (2W) and three wheelers (3W) are important constituents of India's road transport landscape as testified in the following statistics.

- 2W represents 78% of total automobile production and 61% of total petrol sales in India.
- 3W accounts for about 28% of total diesel consumed by the transport sector.
- Sales of 2W and 3W combined have registered an impressive growth of 7.76% CAGR[viii] over the period 2012-13 to 2017-18, more than the overall rate of increase in vehicle sales.

In future as well, the 2W and 3W sales are envisaged to continue rising, driven by growing population, shortage of reliable public transport having last mile connectivity and the need for a budget friendly transportation mode. Hence, to initiate for the first time a consumer awareness program about the impact and real cost of owning a vehicle, it makes sense to target 2W and 3W segments. After setting some momentum, the program can be potentially rolled out for 4 wheeled passenger cars and rest of the vehicle segments, including new technologies such as electric vehicles.

CHAPTER 2

Objective and Scope of Green Vehicle Rating (GVR)

While traditional wisdom would count the 80% share of two and three wheelers in India's vehicle fleet as a hurdle in curbing vehicular energy and environmental burdens, but thought otherwise, it presents an opportunity as large as the massive consumer base which is yet to be tapped with simple and open information for bottom-up shift to cleaner and efficient vehicles. And this is the central thought of GVR - to constructively raise awareness of consumers[ix] on vehicle emissions and impacts of fuel efficiency with clear public information, resulting from credible methods and analyses.

GVR serves as an information tool that identifies vehicle models with high to low environmental performance in the 2 and 3-wheelers segments. It enables consumers to see the hidden costs of energy-related pollution impacts from vehicular fuel combustion to inform their purchase decisions. In its current phase, GVR evaluates the tail pipe emissions from

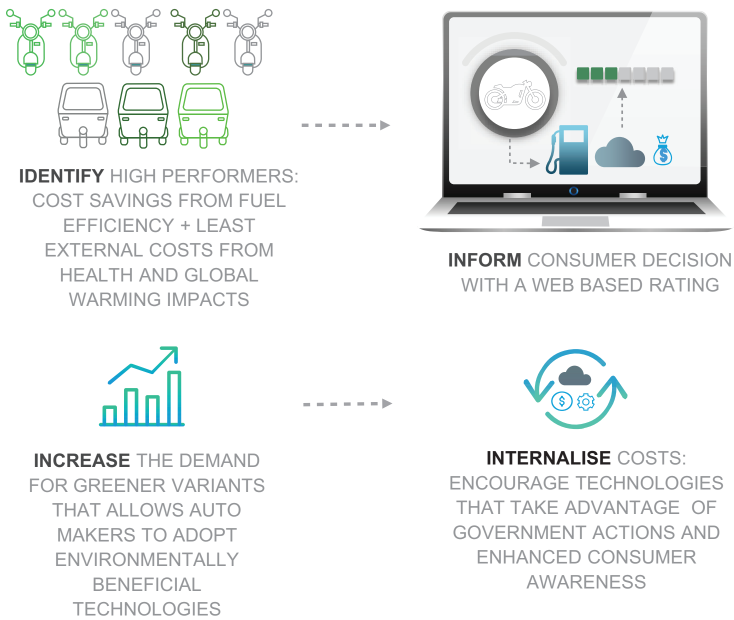


Figure 2.1: Benefits of Green Vehicle Rating for consumers, industry and the government

a pilot size sample of twenty-two new vehicle models, including top sellers: twenty 2-wheelers, two 3-wheelers. This pool included products from Bajaj, Hero Motors, TVS, Honda, Suzuki, and Eicher.

The main outcomes of GVR cover two dimensions: 1) Ranking for 2 and 3-wheelers so that consumers can compare between the negative contributions of highest and least polluting models, developed by rating against the environmental and health impacts of a reference vehicle; 2) Expanding the current understanding of consumers beyond the costs of owning a vehicle, termed as 'Total Cost of Ownership' (TCO), to getting them to value[x] and account for social costs generated from greenhouse gases and air pollutants in monetary terms (₹ per Km). Current ranking is for models manufactured in 2017, and it may alter as vehicle technologies improve and more stringent emissions and fuel quality norms are applied.

Many stakeholders stand to benefit from the Green Vehicle Rating, including automakers and policymakers (see Figure 2.1). Once consumers have sound information to easily identify the high performers from lower ones, they will be able to the benefits of the cleaner models. This will aggregate public willingness to adopt pollution controlling vehicular technologies, which will allow automakers to altering their manufacturing practices more efficient engines, and pollution control devices in vehicles. The growth in consumer awareness will act as support for government initiatives on emissions norms, fuel quality upgrades and vehicle maintenance and pollution control requirements

The GVR outcomes, the final rating and per vehicle cost analysis, are listed in this report in Chapter 5 and are also displayed for public knowledge on the project web pages within AEEE website. Although not a part of the project scope, AEEE also created a set of multi-media collaterals to be used on social media and web pages, to communicate the analysis done in the following chapters and its underpinnings, such as the Form 22 data, to the consumers, who are the primary audience of this work, and also to policy makers and auto manufacturing community in India.

Composite analysis of fuel efficiency and criteria pollutant levels

Impacts from both air pollutants (NOx, CO, HC, PM), and greenhouse gases (GHGs) such as CO_2 are evaluated compositely to take into account both localized damages that emanate from air pollutants and that directly hamper the exposed population, and the global effects such as climate change, respectively. Fuel efficiency and emissions from a vehicle cannot be looked in isolation. Diesel vehicles provide a compelling example: while they are known to be considerably more fuel efficient than gasoline vehicles, resulting in low greenhouse gas impacts, diesel vehicles release higher quantities of NOx and particulates and pollute local air quality. While fuel efficiency values are well-known and valued by consumers in their decision making, emission data listed on Form 22 is not in a usable and applicable format for the budget calculation.

Vehicle air pollution and carbon emissions are a negative externality with numerous[xi] depleting impacts such as reduced reproductivity of the ecosystem (wetlands, crops and vegetation), eutrophication, acid rains, warming climate and resulting harms, and direct health impacts that increase mortality and morbidity. Out of these, GVR addresses and evaluates the impacts on public health, climate change, visibility and smog that directly affect consumers and aid in addressing the current challenges facing metros in India. 2 and 3 wheelers are predominantly used in dense urban cities proximal to human settlements, because of which their tail pipe emissions have extremely high exposure to human beings. As a result, the deterioration of air pollution is significantly higher in magnitude[xii] than those from the release of carbon dioxide, which contribute to global warming, though not without domestic impacts.

Owing to high localized damages and in comparison to weightage factors used in other ratings, health impacts are assigned higher weighting than environmental impacts in the composite analysis in GVR. The impacts evaluated and weightage factors considered in other international ratings have been discussed in Chapter 3 and compared with GVR's in Chapter 4.

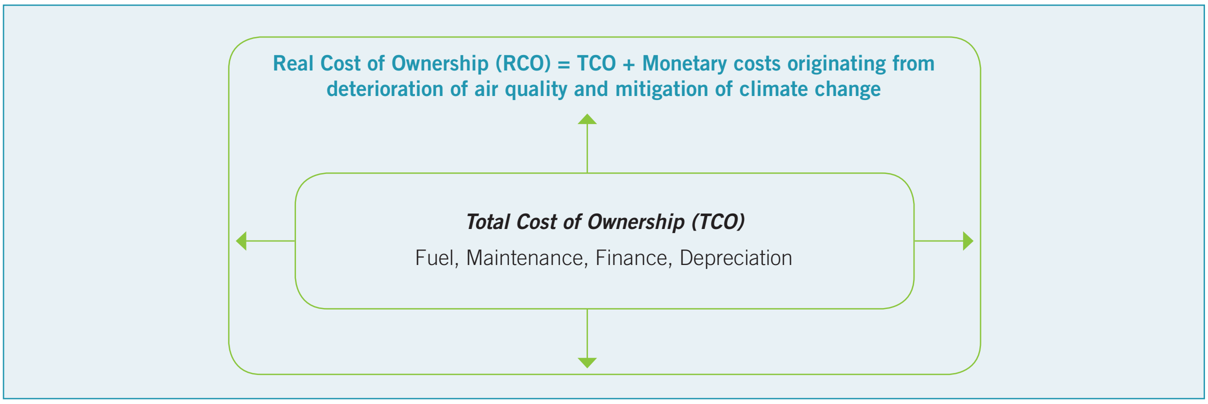
Public information to account external costs from vehicle fuel use and emissions

While purchasing vehicles, consumers take into account the mileage and upfront costs as they form the majority share in the overall costs. External costs of motor vehicles due to pollutants and greenhouse gases emitted are not valued by consumers because of a host of factors: lack of adequate information in public domain and difficulty in comprehending emissions data in their purchase decision, to name a few. Hence, GVR attempts to expand the definition of the TCO such that consumers are enabled to include monetary costs of damages on public health, local environment and global climate change from fuel inefficient and polluting vehicles.

To make these impacts clearly visible and understandable across consumer segments, a damage cost approach is used to convert the negative contributions into monetary terms. Monetary figures are invariably grasped and are more usable for a consumer, as opposed to mass of pollutants and gases. In the damage cost method, the marginal cost of mitigating damage from the release of one unit of an air pollutant and a GHG is aggregated to find the total costs of damages produced, also known as the external costs. This approach is commonly used in economic evaluation of environmental deterioration and has also been used in other international vehicle ratings. It relies on availability of region specific damage cost factors of criteria pollutants. While original calculations of the cost factors weren't a part of the scope of this project, and neither was the case in other international ratings which benefitted from region-specific and advanced research studies and extensive government-led efforts on this topic.

However, to plug-in this gap to the best possible extent, AEEE carried out literature reviews to devise a method for secondary analysis and estimate the damage cost factors of air pollutants in India, which led to discovering the only study done in India on this topic, Sengupta and Mandal (2002)[xiii] at National Institute of Public Finance and Policy. While Sengupta et al were limited by lack of primary data and could only produce a secondary analysis, but their working paper offered a benefit-transfer method, which was borrowed for GVR. The damage costs factors calculated were further validated by interviewing the author of the aforementioned study[xiv].

Lastly, MoRTH's amendment to Central Motor Vehicle Rule 1989 that required auto makers to declare vehicle pollutant data on Form 22, from April 2017 onwards, is the source of primary data on vehicle air pollution for this project. While data disclosure of type approval data on Form 22 is a highly encouraging move, it has a caveat. In the case of petrol vehicles, data on particulate matter is not declared, whereas for diesel vehicles it is. BS IV emissions norms for two and three wheelers do not restrict PM emissions. To the best of the author's knowledge, this is why, type approval tests for vehicles do not include measurement of PM and are not declared on Form 22. As a result, PM data had to be excluded from GVR calculations. However, with enforcement of BS VI, which will regulate PM from petrol vehicles, it is highly likely that Form 22 will carry particulate matter data as well. Literature review was done to identify dependencies between other pollutants (NOx, CO, HC) and PM, but it instead elucidated that each pollutant from a motor vehicle needs to be measured individually.



The precedent research illustrated that most of international rating systems evaluate the lifecycle impacts of motor vehicles. This is in large parts due to availability of official data and presence of other indigenous estimates that provide data on upstream and downstream emissions. The case is evidently different in India. The advent of GVR was led by the amendment in Form 22 for public disclosure of vehicle pollutant levels and remains the only government authorised record in public domain on pollutants emitted from vehicle tail pipes in India. Analysing lifecycle emissions is critical and warrants further studies. But to kick-start this first time effort of comparing emissions and environmental impacts of vehicles to get consumers to pay attention to the impacts of their purchase decisions, GVR uses the official figures on tail pipe data from Form 22 to focus on 'Tank To Wheel' emissions and fuel efficiency. Subsequent versions of GVR may be expanded with components of 'Well to Wheel' emissions.

CHAPTER 3

Review of International Vehicle Ratings Programs

The following text provides an analysis of precedents of vehicle rating programs operating in other regions of the world. Following ratings have been considered: ACEEE's greenercars.org methodology, UK's Next Green Car (NGC), Belgium's ecoscore.be, Clean Vehicle Europe (CVE), Australia's Green Vehicle Guide (GVG), and New Zealand's Next Right Car.

Such rating programs have allowed consumers in the respective countries to make better choices[xv] while purchasing vehicles - in terms of emissions, fuel consumption, safety, etc. For instance, accessible information allows consumers to see the benefits of cleaner and efficient models, and acting as a form of demand side intervention, which attempts to create a market for less polluting vehicular technologies. Automakers can tap into this demand to transition to more efficient technologies.

Evidence[xvi] 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, 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.

Each of the international rating programs have been dissected in Table 3.1 and Table 3.2 to understand and compare their origin and management (government/private/joint), regional scope (country/ continent), 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), as summarized in Table 3.2, a technical analysis was done to understand the analytical framework used for calculating the environmental performance of the vehicle, types and sources of data and cost factors pertinent to regional geography and demographics, types of impacts of air pollutants, carbon emissions and noise levels of vehicles.

Out of the six rating programs reviewed, three were based on a damage cost method to convert the negative consequences from air pollutants and greenhouse gases into monetary losses for consumer understanding. These were ACEEE's greenercars.org, Belgium's Ecoscore and UK's NGC. While others such as Australia's GVG and New Zealand's Right Car directly use emission levels to rate the vehicles, avoiding monetary characterisation of environmental externalities that damage health and economic development in communities. In terms of the types of emissions considered, while these three ratings accounted for lifecycle emissions (well to wheel emissions), others were limited to tail pipe emissions. None of the rating programs reviewed have ranked two wheelers, but only cars and other light duty vehicles.

In terms of the variation in the governance of rating programs: some have been initiated and are being run by the government, such as those in Australia and New Zealand, while others have been created and managed entirely by private or not-for-profit organisations, such as NGC in the UK and ACEEE's in the US, respectively. Others such as Belgium's Ecoscore were created by research universities, but were initiated by the government.

Mapping the sources of emissions data, almost all of the ratings programs benefit from government authorised homologation data and results of type-approval testing available in public domain. For example, ACEEE relies on EPA's Supplemental Federal Test Procedures[xvii] (SFTP) results, whereas others such as NGC combine the UK certification agency data and data collected through Portable Emissions Measuring Systems (PEMS) in partnership with an independent data and testing firm[xviii], Emissions Analytics, to gauge real world emissions levels.

In the ratings accounting for vehicular environmental damages in monetary terms, additional data on cost factors of externalities from air pollutants and carbon dioxide was required, which in majority of cases was obtained from expert-led primary research studies and extensive projects (such as ExternE in the case of Ecoscore, and social costs evaluation for motor vehicles in the US). While the existence and use of such statistics is a relatively common practice in policy making and public consumption in some countries, there is a lacuna of corresponding primary research in India, which created gaps in data and economic analyses of vehicle emissions while developing GVR. However, with the help of literature reviews, methods were devised to plug in the shortfall in availability of damage costs factors.

Because the aim of GVR is to enable consumers to account the vehicular environmental damages as they process the cost of ownership prior to purchasing vehicles, GVR adopted a damage cost based method to rate the negative impacts of emissions rather than the emission levels, which are difficult to comprehend for consumers. This approach, adopted by greenercars.org, Ecoscore and NGC in US, EU and UK, respectively. These were used to guide the framework of rating vehicles in GVR. Ideas drawn from this precedent research have been specified with GVR methodology and steps in chapter 5. Other approaches such as those used in Australia directly and only use the greenhouse gas emissions levels for rating vehicles, which wasn't deemed adequate for raising consumer awareness which was the goal in GVR.

Table 3.1: International vehicle ratings: *General features*

Name and Country	Developing Agency of the rating (Government/ Private/Joint)	Format of Dissemination	Approach (Well to wheel, Tank to Wheel)	Fuel Types	Vehicle Types
EcoScore (Belgium)	Developed by 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
Next Green Car (UK)	Privately developed by Auto consultants Next Green Car	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
ACEEE's greenercars.org (US)	Privately developed by ACEEE	Web based calculator: https://greenercars.org/greenercars-ratings	Well to Wheel (tail pipe, upstream) + Embodied emissions	Gasoline, diesel, PHEV, EV, CNG, Fuel cell	Cars and light trucks

Table 3.1: International vehicle ratings: *General features*					
Name and Country	Developing Agency of the rating (Government/ Private/Joint)	Format of Dissemination	Approach (Well to wheel, Tank to Wheel)	Fuel Types	Vehicle Types
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): there is a possibility that CVP has been discontinued: http://www.cleanvehicle.eu	Tank to Wheel = Tail pipe emissions	Petrol, diesel, PHEV, BEV	All kinds of road transportation
Green Vehicle Guide (GVG) (Australia)	Government: Department of Infrastructure and Regional Development	Web based calculator: https://www.greenvehicleguide.gov.au/# • Assists consumers in sorting vehicles based on CO_2 emissions, air quality standards, fuel costs.	Tank to Wheel	Petrol, diesel, LPG, Electric and Plug In Hybrid	Cars
Rightcar NZ (New Zealand)	Government: NZ Transport Agency	Website: http://rightcar.govt.nz/co2-ratings.html Vehicle are ranked through three ratings - air quality, fuel economy and CO_2 rating.	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

Table 3.2 : International vehicle ratings: *Technical features*						
Name of the Rating	EcoScore (Belgium)	Next Green Car (UK)	ACEEE's greenercars.org (USA)	Clean Vehicle Europe (CVE) (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, PM_{10}, SO_2,	CO, HC, NO_x, PM_{10}, SO_x	NOx, PM and NMHC	None	CO, HC, NOx, PM10 (only for diesel models)
GHG Emissions	CO_2, CH_4, N_2O	CO_2 Indirect emissions: N_2O, CH_4, CO_2	CO_2, HC, NO_x, CO, CH_4, N_2O	CO_2	CO_2	CO_2

Table 3.2 : International vehicle ratings: *Technical features*						
Name of the Rating	EcoScore (Belgium)	Next Green Car (UK)	ACEEE's greenercars.org (USA)	Clean Vehicle Europe (CVE) (Europe)	Green Vehicle Guide (GVG) (Australia)	Rightcar (New Zealand)
Source of Emissions Data	Dutch 'Rijksdienst voor Wegverkeer' (RDW);Since quite some years, RDW collects emission data of all vehicle models available in Europe. RDW data is combined with 'Dienst Inschrijving Voertuigen' (DIV) which provides new registration data on a regular basis. This data is used to update Ecoscore database every two months.	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). To compensate for under prediction of test results, EPA averages results over the lifetime of the vehicle		Data from Australian Design Rule (ADR) 81/02 to determine both fuel consumption and CO_2 emissions + information on the vehicle's certified air pollution standard (from the ADR 79 test) + data provided from the ADR 83/00 stationary noise test is submitted by manufacturers (on a voluntary basis) for publication on the GVG website.	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	• Global Warming Potential (GWP) for GHG emissions • External costs for impacts on human health from pollutants • Noise levels in dB(A)	Aggregated external impacts are valuated for each emission type.	Monetary damage costs on human health from each emission type are calculated. Environmental Damage Index (EDX) is calculated for each emission.	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
Source of External Costs from Pollutant Emissions	ExternE Project: Commissioned by EU Commission for a scientific assessment of external costs from air pollution in EU region. Global warming potential is computed based on IPCC methods.	ExternE, Emissions Analytics (This rating argues that ExternE numbers are not accurate)	Delucchi and https://cloudfront.escholarship.org/dist/prd/content/qt43s6n28v/qt43s6n28v.pdf	ExternE, (Clean Air for Europe) CAFE, HEATCO studies	Emissions are not converted to monetary costs	Emissions are not converted to monetary costs

Table 3.2 : International vehicle ratings: *Technical features*						
Name of the Rating	EcoScore (Belgium)	Next Green Car (UK)	ACEEE's greenercars.org (USA)	Clean Vehicle Europe (CVE) (Europe)	Green Vehicle Guide (GVG) (Australia)	Rightcar (New Zealand)
Normalisation	A reference vehicle following Euro IV standards is used for normalisation	The methodology 'normalises' the external costs by dividing the total external cost by a 'maximum' value (which represents a high polluting vehicle).	A pre control vehicle (highly polluting vehicle) is used for normalisation	No normalisation, hence no rating; Only costs incurred from damages caused by emissions are given as Operational Lifetime Costs (OLC)	None	None
Weighting	• 40% Air quality: 20% human health + 20% ecosystems damage, 50% Climate change, 10% Noise. This results in Total Impact (TI) • Only air quality impacts are converted to monetised costs.	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)	QCO_2 (CO_2 external cost in €/km) = (TPxEC) +(FPxEC) +(VPxEC) NGC Rating (CO_2) = 100 x QCO_2 (external cost) ÷ QCO_2 ('max' external cost) Similarly, external costs and rating for all of the emissions are calculated and combined to form the final rating.	EDX is converted into Green Score through an inequality formulae.	OLC_{PM}= 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 (lowest to highest), followed by extra urban CO_2 (lowest to highest), energy consumption (lowest to highest), electric range (highest to lowest), air pollution standard (highest to lowest), noise (lowest to highest)	

Table 3.2 : International vehicle ratings: *Technical features*						
Name of the Rating	EcoScore (Belgium)	Next Green Car (UK)	ACEEE's greenercars.org (USA)	Clean Vehicle Europe (CVE) (Europe)	Green Vehicle Guide (GVG) (Australia)	Rightcar (New Zealand)
Sources	• http://eco-score.be/files/Analysis_CarFleet2016.pdf	• http://www.nextgreencar.com/content/NGC-UK-Vehicle-Ratings-2016-v2-2.pdf	• https://cloudfront.escholarship.org/dist/prd/content/qt43s6n28v/qt43s6n28v.pdf • http://aceee.org/research-report/t111 (Report)	• http://eco-score.be/files/Comparison%20of%20Clean%20Vehicles%20Portal%20with%20Eco-score.pdf	• http://www.greenvehicleguide.gov.au/pages/Information/RankingAndMeasurement	• http://rightcar.govt.nz/economy-ratings.html

CHAPTER 4

Emissions and Fuel Economy Norms and Programs in India

Vehicle rating programs, the foci of this report, allow consumers to make informed vehicle purchases, but they are not sufficient by themselves in driving the demand for less fuel consuming and clean vehicles. They are most effective when complemented by policy context marked by tight fuel efficiency standards and emissions norms, fiscal incentives at both production and consumption side, stringent vehicle test conditions and regulations for open data on CO_2 and criteria pollutant levels, to list a few.

Although the scope of this report did not extend itself to an in-depth analyses of supporting policy measures, Table 4.1, 4.2 and 4.3 provide a summary of the existing emissions norms - the current Bharat Stage emissions norms[xix] and fuel consumption standards. This is followed by an overview of vehicle fuel economy labels, another form of consumer information program.

Table 4.1: Emissions norms for two wheelers in India

Vehicle Category: Two-Wheelers

Stage	BS IV			BS VI↑	
Implementation Date (type approvals)	2016.04*			2020.04*	
Class †/ Engine Category	Class 1 & Subclass 2-1	Subclass 2-1	Subclass 3-1 & 3-2	SI Engine	CI Engine
CO	1.403	1.97	1.97	1	0.5
HC	–	–	–	0.10a	0.1
NOx	0.39	0.34	0.2	0.06	0.09

Table 4.1: Emissions norms for two wheelers in India

Vehicle Category: Two-Wheelers						
HC+NOx	If Evap. test ≤2g/test	0.79	0.67	0.4	–	–
	If Evap. test ≤6g/test	0.59	0.47	0.2		
PM		–	–	–	0.0045‡	0.0045

Table 4.2: Emissions norms for three wheelers in India

Vehicle Category: Three-Wheelers				
Stage		BS IV	BS VI↑	
Implementation Date (type approvals)		2016.04*	2020.04	
Class †/ Engine Category		CI Engine	SI Engine	CI Engine
CO		0.38	0.44	0.22
HC		–	0.35	0.1
NOx		–	0.085	0.1
HC+NOx	If Evap. test ≤2g/test	0.38	–	–
	If Evap. test ≤6g/test			
PM		0.0425	–	0.025

Table 4.3: Fuel consumption standards for passenger cars in india

Notification	Compliance Year	Corporate Fuel Consumption Standard	Energy Savings by end of 2025
Fuel Consumption Standard	2017-18	5.5 l/100 km ($129.8\ gmCO_2/km$) @1037 kg	22.97 million toe
	2022-23	4.78 l/100 km (113.0 $gmCO_2/km$) @1145 kg	

Fuel Consumption Standards: For four wheelers, the Bureau of Energy Efficiency (BEE), the policy and strategy arm of Ministry of Power in India has set the current CO_2 emission standard at 130 gm per km (20 km/L), which by 2021-2022 will be reduced to 113 gm per km (18.2 km/L)[xx]. However, these are much weaker in comparison to European standards which are targeting a fleet average of 95 gm per km by 2020, US Corporate Average Fuel Economy (CAFE) standards with a target of 91 gm per km for 2020 (although this target is under review).

While fuel economy norms for two wheelers are listed as one of the transport activities being done by BEE, they are yet to be officially declared and enforced. Fuel economy norms are regulated under the Energy Conservation Act of 2001 and designed and implemented by the BEE. Effective April 2018, BEE has also enforced diesel consumption norms[xxi] for heavy-duty vehicles (HDV), exceeding twelve tonnes in gross vehicle weight, within the ambit bestowed by the EC Act.

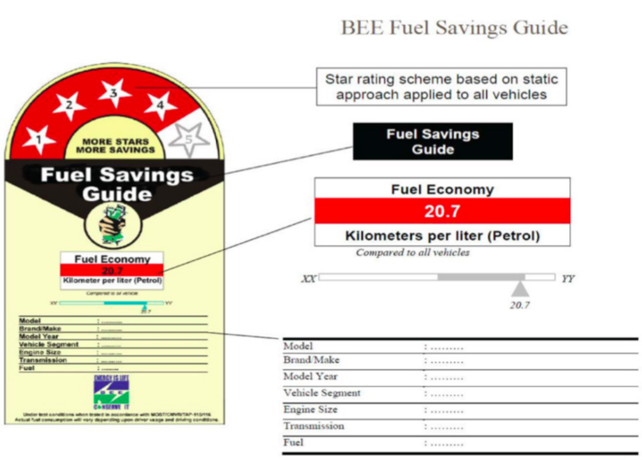


Figure 4.1: **Fuel economy label for cars in India under production at BEE**

As a complimentary policy strategy, a majority of vehicle markets studied in Chapter 3 also use Vehicle Fuel Economy Labelings (VFEL) to inform consumers about the fuel saving potential of vehicles and drive the demand for efficient vehicles, and enhancing the efforts of government on increasing fuel efficiency. For example, the US and the UK have a mandatory fuel economy labelings program since late 1970s. These labels are either displayed on the car or the showroom and carry key numbers: the efficiency levels in urban and rural areas, fuel costs and greenhouse gas (tail pipe) levels of the vehicles either on the car or in the showroom. In nearly all of the countries with vehicle ratings in chapter 3, there are mandatory fuel economy labelings programs that lend support to the goals of rating programs.

India's first mandatory vehicle fuel economy labelling program for passenger cars is under production at the BEE (see Figure 4.1)[xxii]. The label follows a star rating format developed on the basis of fuel efficiency test data from Automotive Research Association of India (ARAI), a testing agency of the government. Fuel economy labels of the US[xxiii] and UK[xxiv] are given in Figure 4.2 and 4.3 for a broad visual comparison.

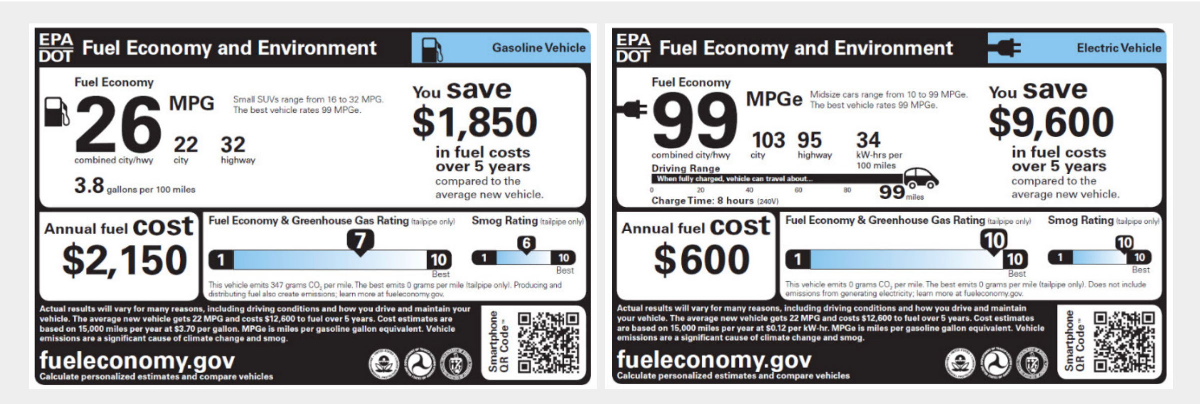


Figure 4.2: Fuel economy labels in the US; Top - conventional gasoline engines, bottom - electric vehicles

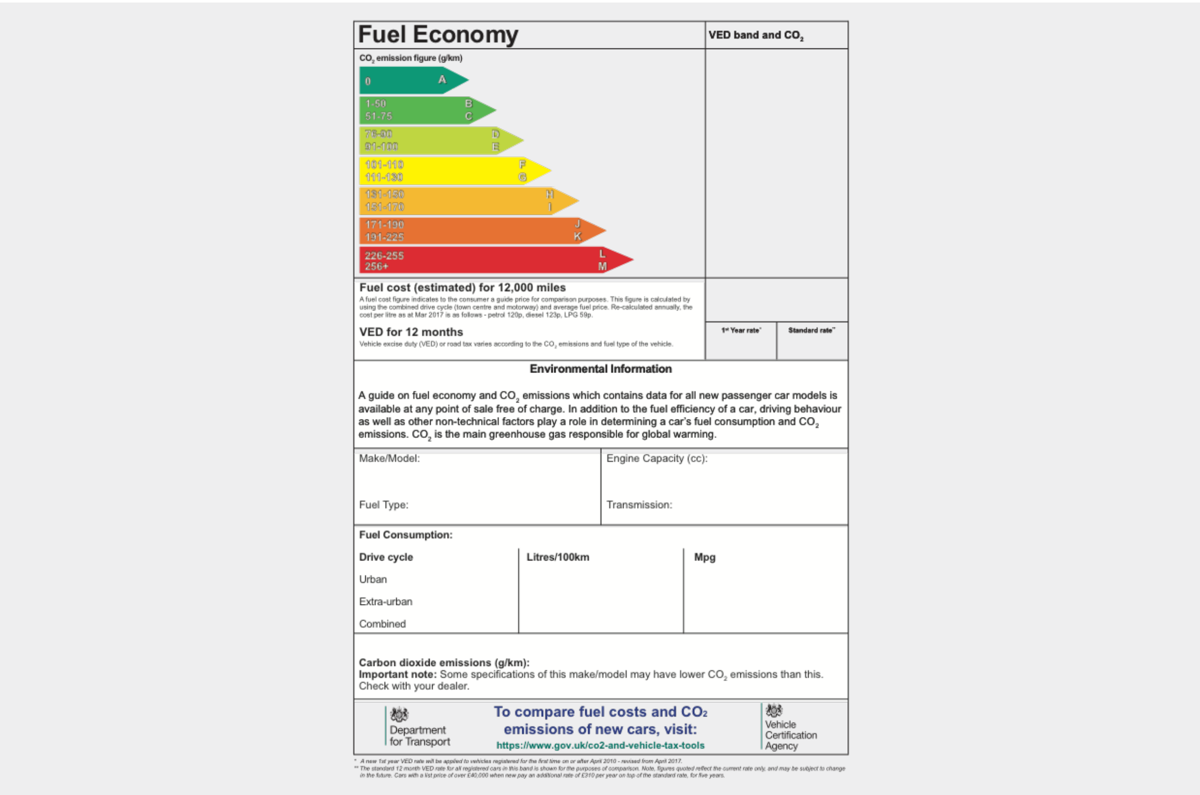


Figure 4.3: Fuel economy label in the UK

CHAPTER 5

Methodology of GVR

Five steps, devised from research on international rating instruments and pertinent literature[xxv] [xxvi], were used to rate the vehicles in GVR. These included: data survey and inventory creation, classifying impacts, characterising impacts in monetary values, normalisation and weighting. Each of these steps are described as follows.

Step 1: Data Survey and inventory

GVR considers 'Tank to Wheel' (TTW) emissions, for both air pollutants and GHGs, which are released from the tail pipes of vehicles upon combustion of fossil-fuels. The emissions considered in the GVR inventory are listed in Table 5.1.

Table 5.1: List of GHGs and pollutants considered in GVR

Air Pollutants	Greenhouse Gases (GHGs)
Mass in gram per Km	***Mass in gram per Km, converted to CO_2e***
Carbon Monoxide (CO)	Carbon Dioxide (CO_2)
Hydrocarbons (HC)	Methane (CH_4)
Nitrogen Oxides (NOx)	
Particulate Matter (PM)*	
Source of data	
Form 22 'Road Worthiness Certificate'	Self reported fuel efficiency values from auto dealers and online market places
* PM data is only available in the case of diesel vehicles	

Form 22: In the case of air pollutants, the volume of emissions in gram per km have been taken from the Form 22 that 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). As a first-time effort on vehicle emissions data disclosure in India, since April 2017, auto manufacturers are required by the Ministry of Road Transport and Highways (MoRTH) of the Government of India to declare the pollutant levels of each vehicle model that they produce on the Road Worthiness Certificate, also known as the ‘Form 22’. For vehicles running on Petrol/CNG/LPG/Electric/Hybrid vehicles, the pollutants included in Form 22 are: CO, HC, Non Methane HC, NOx, HC+NOx. Auto makers are required to declare PM levels only in the case of diesel vehicles. Type Approval tests are done to measure the pollutant levels at government authorised testing agencies across India. Once the pollutant levels are determined, auto manufacturers sign the Form 22 and hand two copies per vehicle model to the auto dealers - one for vehicle registration at the Regional Transport Office (RTO) and another one as a consumer copy.

Survey for Collecting Form 22: AEEE began by surveying auto dealers to collect Form 22 for a pool of 10-15 top selling 2 and 3-wheeler models. Only auto dealers in Kerala shared Form 22. Dealers in Delhi (2) and Kolkatta (1) were either reluctant to share the Form 22 or were unaware about it or did not immediately recognise the name ‘Form 22’. AEEE also wrote directly to auto manufacturing companies on their corporate email addresses and press inquiry forms available on their websites with requests to share Form 22 of selected models. 26 such inquiries were made without success. Therefore, AEEE launched an outreach exercise within the personal and professional networks of its own personnels to source Form 22. With this network outreach exercise, AEEE managed to collect Form 22 for twenty 2-wheelers and two 3-wheelers.

Unlike the emissions values for pollutants given in Form 22, no official data on fuel efficiency is available in the public domain in India. Hence, to find the emissions values for GHGs, the unofficial fuel economy figures (in Km per Litre) that are self reported by auto dealer websites, well-known online market places such as bikewale.com, droom.com were referred. After obtaining the fuel efficiency value, an adjustment factor was used for accounting the loss in fuel efficiency levels in on-road conditions. This is mainly due to inconsistencies between on-road and test conditions for measuring fuel efficiency. Other ratings systems also use an adjustment factor to bridge this gap. While there are no research studies that provide an adjustment factor for the Indian conditions, based on a broader understanding of the discrepancy between test figures vs on-road performance of vehicles, it has been assumed that fuel efficiency is 30% lower on the road than in the test conditions.

Next, the carbon content in the fuel used per kilometre travelled was calculated to arrive at the estimations of CO_2 emissions factors (gram per L) for BS IV fuels in India. Table 5.3 estimates the mass of carbon dioxide emitted per litre of motor fuel consumed by a vehicle in India, based on BS IV fuel density levels. This will be used with the fuel efficiency number acquired from auto websites to find CO_2 emitted for every kilometre that a vehicle runs. Main formula[xxvii] used is: Emission factor (Gram CO2/unit)[xxviii] = Default carbon content[xxix] * Oxidation factor * Default Net calorific value * Carbon molecule mass ratio (44/12) * Fuel Density[xxx, xxxi]

Other technical specifications of vehicle models such as ex-showroom price, engine displacement, class, BS norm was collected from a combination of auto manufacturer websites and online marketplaces. All of this information, and the levels of air pollutants and greenhouse gases were recorded for each 2 and 3-wheeler to build a **‘Vehicle Matrix’**, the main outcome of Step 1 (Table 5.2).

Step 2: Classifying the impacts of GHGs and criteria pollutants

Vehicles engines combust fuel (petrol, diesel, CNG, LPG) and the engine partially converts this energy to power the vehicle. In the process, the tailpipes release pollutants (CO, HC, NOx, PM) and greenhouse gases (CO_2, CH_4, N_2O). While these emissions are a natural by-product of a fuel combustion process, but mainly three interdependent factors[xxxii] are responsible for the origin of excessive emissions that are beyond the safe thresholds of ambient air quality and the targets set for mitigating emissions, and the overall magnitude of the emissions produced and damages accrued. These are:

Table 5.2: Vehicle matrix

Technical Specifications									Pollutants data from Form 22			
Type	Model Name	Bharat Stage emissions standard	Price (Ex showroom in Delhi)[1]	Fuel Efficiency	Engine Size	Kerb Weight	Fuel Type	Commonly- known Total Cost of Ownership (TCO)	Carbon Monoxide (CO)	Hydrocarbons (HC)	Nitrogen Oxides (NOx)	Particulate Matter (PM)
Unit			₹	km/litre	cc	kg		Avg. ₹/km	gm/km			
Two Wheelers												
Scooter	**Honda Activa 4G**	IV	₹ 51460.0	60	109.2	108	petrol	2.23	0.118	0.155	0.186	—
Motorcycle	**Honda CB Shine**	IV	₹ 56429.0	65	125	120	petrol	2.14	0.162	0.226	0.237	—
Motorcycle	**Honda CB Shine SP**	IV	₹ 62032.0	65	124.73	124	petrol	2.17	0.551	0.202	0.154	—
Motorcycle	**Hero Splendor Plus**	IV	₹ 48520.0	81	97.2	109	petrol	1.82	0.144	0.195	0.270	—
Motorcycle	**Hero Super Splendor**	IV	₹ 57190.0	75	124.7	121	petrol	1.87	0.255	0.166	0.320	—
Motorcycle	**Hero Splendor iSmart 110**	IV	₹ 54080.0	75	109.15	115	petrol	1.85	0.379	0.219	0.292	—
Motorcycle	**Hero HF Deluxe**	IV	₹ 47506.0	83	97	110	petrol	1.73	0.144	0.195	0.270	—
Motorcycle	**Hero Glamour**	IV	₹ 56847.0	55	124.7	125	petrol	1.88	0.522	0.164	0.183	—
Motorcycle	**Hero Passion PRO i3s**	IV	₹ 51796.0	84	97.2	115	petrol	1.84	0.144	0.195	0.270	—
Scooter	**Hero Pleasure**	IV	₹ 46104.0	63	102	101	petrol	2.03	0.480	0.194	0.210	—
Scooter	**Hero Maestro Edge**	IV	₹ 49900.0	51	110.9	110	petrol	1.73	1.069	0.135	0.172	—
Motorcycle	**Hero Achiever**	IV	₹ 65594.0	50	149.1	139	petrol	2.35	0.379	0.219	0.292	—
Scooter	**Hero Duet**	IV	₹ 47250.0	45	110.9	116	petrol	2.20	0.816	0.127	0.192	—

Table 5.2: Vehicle matrix

Technical Specifications									Pollutants data from Form 22			
Type	Model Name	Bharat Stage emissions standard	Price (Ex showroom in Delhi)[1]	Fuel Efficiency	Engine Size	Kerb Weight	Fuel Type	Commonly- known Total Cost of Ownership (TCO)	Carbon Monoxide (CO)	Hydrocarbons (HC)	Nitrogen Oxides (NOx)	Particulate Matter (PM)
Unit			₹	km/litre	cc	kg		Avg. ₹/km	gm/km			
Scooter	**TVS Jupiter**	IV	₹ 49966.0	56	109.7	108	petrol	2.30	0.335	0.150	0.175	—
Motorcycle	**Bajaj Pulsar 150**	IV	₹ 81230.0	65	149	143	petrol	2.09	0.355	0.315	0.270	—
Motorcycle	**Bajaj Pulsar 220**	IV	₹ 94683.0	38	220	155	petrol	2.77	1.263	0.127	0.258	—
Motorcycle	**Bajaj Avenger 150**[2]	IV		45	150	148	petrol	2.72	0.990	0.355	0.270	—
Motorcycle	**Royal Enfield Classic 350**	IV	₹ 135378.0	37	346	187	petrol	3.36	0.590	0.225	0.265	—
Scooter	**Suzuki Let's**	IV	₹ 50701.0	64	112	98	petrol	2.49	1.307	0.147	0.175	—
Motorcycle	**Suzuki Gixxer SF**	IV	₹ 87737.0	40	155	140	petrol	2.76	0.222	0.161	0.271	—
Three Wheelers												
Auto Rickshaw	**Bajaj RE Compact LPG 4S**	IV	₹ 110000.00	30	198.99	368	LPG	2.8	0.082	—	—	—
Auto Rickshaw	**Bajaj RE Compact Diesel**	IV	₹ 200000.00	30	470.5	374	Diesel	2.8	0.178	—	—	0.0254

Notes: Prices in other cities may bring a variation of 10-20%. Fuel efficiency values indicated here are unadjusted, they are adjusted to account for real world driving conditions while performing the final calculations. Technical specifications have been sources from auto company websites and online market places such as droom.com, bikedekho.com and bikewale.com. In the case of two wheelers, the Total Cost of Ownership (TCO) follows the standard market practices, and have been adapted from well-known online TCO calculator, Droom and Autondtv. TCO includes fuel costs (increasing at 1% a month), service charges, maintenance, tyre costs, depreciation and insurance, calculated for a period of 5 years and 2000 kms a month.

1 Automobile company website dated May 2018
2 This model has been discontinued

- ***Source of emissions:*** Type of vehicle (light duty, heavy duty vehicles) and the varying efficiency levels of engines and drive trains. While GVR considers tail pipe emissions only, upstream emissions released during fossil-fuel extraction, production and transmission also feed into the lifecycle impacts of the vehicles. For instance, in the case of EVs, while there are benefits because of no tail pipe emissions, the environmental costs from upstream (production of electricity from burning of coal that contributes to 62% of electricity generation in India), downstream[xxxiii], and end of life emissions cannot be ignored.

- ***Fuel use and fuel mix:*** Type of fuel (Petrol, diesel, CNG, LPG, electricity, renewable energy), and the quality of fuel that is regulated by emissions norms. Diesel powered vehicles have substantially higher environmental damages than vehicles running on other fuel types. For instance, through a chassis dynamometer testing by International Council for Clean Transportation (ICCT) and Center for Science and Environment (CSE) in Delhi, found that diesel powered SUVs produce NOx emissions equivalent of 25-65 small petrol cars[xxxiv].

- ***Locational conditions:*** Topographical, climatic, demographical and socio-economic conditions (increased private vehicle ownership, growing mobility infrastructural needs, age distribution in populace), and regional and national policies such as fuel efficiency standards and emissions norms.

The seriousness of burdens from air pollution and climate change in India are writ large. To aid the urgent need of controlling vehicular criteria pollutants and greenhouse gases, enabling consumers to appreciate the negative impacts of their vehicle purchase on their individual health and wealth being, and the stifling local environmental and economic impacts, can offer a potential salvation. To build consumer understanding, GVR accounts for two classes of impacts: public health and environmental, which are explained in the text and the table below.

- ***Public Health Impacts:*** Prolonged inhalation of air pollutants result in health damages, and slowly increase the morbidity levels in population, leading to early deaths, which exerts heavy economic costs at a national level due to increased medical expenditure of households, loss in productivity due to illnesses, loss in workforce due to early deaths. In GVR, health effects are generated from local pollutants such as NOx, CO, HC, Particulates, which are produced due to fuel burning in vehicles and concentrate adjacent to busy roads where population densities are high[xxxv]. In 2013, air pollution (including both indoors and outdoor pollution) costed 7.69% of the GDP and 1.4 Million deaths. Out of these deaths, 2% were due to the transport-borne air pollution. Ailments due to air pollution include respiratory, cardiovascular ailments and other chronic illnesses, also known as Non Communicable Diseases (NCDs), which account for 71% of deaths every year globally[xxxvi]. For instance, presence of excessive amount of Carbon Monoxide (CO) causes blockage in oxygen supply to the heart and brain[xxxvii]. High concentrations of NOx, a precursor of secondary particulates, cause irritation in oral cavity, bronchial tubes, result in coughing and shortage of breath. NOx are absorbed in the mucous membranes of oral cavities and worsens the conditions of asthma patients[xxxviii]. Children and elderly remain at the greatest risk from the health effects of air pollutants.

- ***Environmental Impacts:*** These category of impacts includes adverse effects from climate warming due to GHGs (CO_2 and CH_4). Human activities dependent on fossil fuel burning produce CO_2, which is the largest contributor of energy-trapping gases that accelerate the natural greenhouse gas effect that aids habitation on earth. Methane, a heat-trapping gas, is the second most significant contributor of climate change. Globally, the transport sector accounts for nearly a quarter of the energy-related carbon emissions. Impacts of global warming include extreme heat, sea level rise and irregular weather pattern. There is also consensus in scientists around the world that GHGs deteriorate human health through vector borne diseases and water related illnesses[xxxix]. Secondly, the class of environmental impacts includes environmental effects such as reduced visibility due to haze in cities, and losses to crops and vegetations due to NOx, HC and VOCs. These pollutants undergo chemical reactions with sunlight and produce ground level or tropospheric ozone, which triggers smog and lung-related ailments. This variety of ozone gas is not the same as stratospheric ozone which on the contrary protects the earth from ultra violet radiations[xl]. There is a strong likelihood that by 2030 Asian countries will witness a three-five fold increase in carbon emissions from transport sector, compared to 2000 emissions levels, if adequate actions to redirect investments towards more fuel efficient vehicles and alternatives for mitigating the steeply rising per capita ownership of private vehicles are not taken[xli]. While both GHGs and air pollutants produce environmental effects, greenhouse gases create global and long term effects that are difficult to control unless at the time of release from the point source, but air pollutants produce localised and promptly visible vicissitudes.

Air pollutants such as NOx, CO, HC (or VOCs) also serve as indirect GHGs. The release of criteria pollutants on the surface and in the atmosphere and their transportation to the troposphere and stratosphere allows them to have non-linear chemical interactions with other climate forcing agents resulting in production of substances that directly accelerate warming, and evolving chemical feedback loops that even alter the lifetimes of GHGs[xlii]. For instance, NOx does not have significant direct radiative forcing (RF), but its presence accelerates the production of hydroxyl (OH) that works in favour of ozone depletion. It also forms nitrate aerosols. Similarly, in the case of CO[xliii], the direct radiative forcing is relatively small, but CO governs the overall abundance of OH in the troposphere and couples with OH to chemically impact CH_4 lifetime, tropospheric O_3 and CO_2 photochemical production. In this way[xliv], change in CO concentration leads to change in ozone and methane concentrations and surface level warming. However, indirect GHGs account for less than 1% of total material impact from a warmer climate. Hence, in GVR the indirect climate impacts of air pollutants have not been considered. The impacts on air-pollutants and GHGs which are accounted in GVR are listed in Table 5.4.

In comparison to GVR, Belgium's Ecoscore[xlv] rating has accounted for ecosystem impacts (damage to agricultural yield, forestry, wetlands, etc)[xlvi] from NOx and SOx. ACEEE's greenercars.org, includes human health impacts from criteria pollutants and greenhouse gases.

Table 5.3: CO_2 Emission factors: Bharat Stage IV petrol and diesel for motor vehicles

Fuel (Litres/ kg)	Default carbon content (Kg/ GJ)	Oxidation 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	44/12	0.748	2294.818
Diesel	20.2	1	43	44/12	0.833	2651.402

*Default values set by IPCC
https://www.jica.go.jp/english/our_work/climate_change/c8h0vm00000137cc-att/Appendix_E.pdf

**As per BS IV fuel specifications: Density of petrol: 720 - 775 kg/cc; Density of diesel: 820 - 845 kg/cc
https://www.iocl.com/Products/MS_BS_IV_Specification%20_Current_.pdf
https://www.transportpolicy.net/standard/india-fuels-diesel-and-gasoline/

Table 5.4: Impacts from GHGs and air pollutants accounted in GVR

	Environmental Impacts			Public Health Impacts
	Climate change	Reduced visibility	Crop losses	
Greenhouse gases				
Carbon Dioxide (CO_2)	✓		✓	✓
Methane (CH_4)	✓			
Air Pollutants				
Nitrogen Oxide (NOx)		✓		✓
Carbon Monoxide (CO)				✓
Hydrocarbon (HC)		✓		✓
NOx + HC		✓	✓	✓
Particulate Matter (PM)		✓		✓

Step 3: Characterisation of impacts as monetary values

For consumers to appreciate and purchase clean and efficient vehicles, energy and environmental costs and economic benefits need to be straightforward information. While bringing this information to the foreground seems to be the most obvious policy intervention for the existential risks from energy-related pollution in India, but there is shortage in information that consumers can use to weigh the economics of the health and environmental effects of vehicles. GVR puts an economic lens on the effects of tail pipe air pollution and greenhouse gas emissions, as a first time effort in India, by ascertaining the monetary value of vehicle damages on human health, climate and environment in per kilometre (₹/Km), which are calculated by multiplying the mass of emissions[xlvii] (in g/Km) with the marginal damage cost (₹/gm) for each emission.

Impacts from air pollutants (sourced from Form 22) have been quantified in monetary terms with a damage cost method, which reflects the damages and risks (losses to health, visibility and crops) estimated in terms of costs per unit (gm, kg, tonne) of air pollutants. Damage cost factors vary by pollutants and by region/country. Impacts from GHGs (CO_2, CH_4) (sourced from fuel efficiency value) are monetised by using the Social Costs of Carbon Dioxide (SCC). Prior to carrying out calculations to quantify the impacts, AEEE carried out literature reviews to compile and/or estimate the SCC and the marginal damage costs of air pollutants in India. While original calculations of these costs weren't a part of the project scope, AEEE and neither in other international ratings however, offers informative research that shines light on prominent studies, methods, and finally the research gaps that hinder this areas of work described in the conclusion of this report.

Most of the other international vehicle ratings benefit from region-specific research studies and government-led projects to determine the damage cost or social costs factors of vehicular environmental externalities. In the case of motor vehicle use, social costs include underpriced costs due to air pollution, external and non market costs. Data proficient governments use these cost factors to establish the costs to benefit ratios of energy and environmental regulations, and hence, have quantitative analytics readily available for policymakers, researchers and for public knowledge which support the creation of information programs such as vehicle ratings and fuel efficiency labelings.

International examples on studies on damage cost factors include the ExternE[xlviii] project of the European Commission, an extensive study started in early 1990s to quantify the external costs of energy from carbon intensive sectors such as transportation for member countries, which have been used for Belgium's Ecoscore and the UK's Next Green Car ratings. An Impact-Pathway approach is used to find the external costs of both GHGs (CO_2) and air pollutants in ExternE.

Examples in the United States include a series of scholarly research reports by McDeluchhi et al 1991[xlix] that estimated the social costs of motor vehicles from air pollution impacts on health, visibility, agricultural yield, which have been used in calculation of Environmental Damage Index for vehicles in ACEEE's greenercars.org rating. Primary work is done for quantifying impacts from air pollutants, and a secondary research is used for CO_2 impacts. However, as a consequence of the varying accounting systems, analytical methods and sources of data, the estimates of social costs of vehicular air pollutants have a tendency to suffer from striking debates.

Calculating the Damage Cost Factors from Air Pollutants in India: Sengupta and Mandal (2002)[l] remains the only working paper produced in India that derives the health damage costs from air pollution released 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 plug the gap in primary analysis on marginal costs of foregone environmental resources and public health due to vehicle emissions in India. This method allows for quantified results from one policy site to become endogenous for other policy site by incorporation of the new regional factors, such as the physical and demographical characteristics of a region that alter the concentrations of criteria pollutants[li]. Most other studies[lii] on economic analyses of transport air pollution in India have relied on these estimates. To execute the Benefit-Transfer Method, Sengupta and Mandal (2002) made corrections for variations in the Gross Domestic Product (GDP), Purchasing Power Parity (PPP), per capita income in India, and population density. Most importantly, an in person interview was conducted with the author of the working paper who validated the damage costs factors derived below with the corrective steps used in his paper[liii] and also made recommendations for future work in this area, some of which has been described in the final conclusion of this report.

To calculate the marginal damage costs of air pollutants for the year 2016, GVR adapted the four corrective steps used by Sengupta and Mandal (2002) to 1991 US costs estimated by McDelucchi et al. The steps are as follows:

Step 1: First, the US dollar costs of emission per kilogram of different pollutants in 2016 US prices are obtained from the corresponding cost estimates at 1991 prices by using the inflation in US GDP deflator between 1991 and 2016 and then convert it into Indian rupee by using the US dollar exchange rate into Indian rupees for 2016.

Step 2: Second, the ratio of Indian GDP in US dollars to the same in PPP (purchasing power parity) dollar – that is, the PPP dollar-rupee exchange rate – is used for adjusting the cost estimates of step (i) for the difference between the purchasing power of the US dollar and the Indian rupee in 2016. India 2016 PPP = 17.447; Ratio of Indian GDP in US dollars to the same in PPP (purchasing power parity) dollar = 0.26

Step 3: Third, to adjust for the variation in per capita real income between the US and the Indian cities, the ratio of per capita income for India to the US per capita income in PPP dollar in 2016 is used to adjust the costs obtained in step (ii). (per capita income in 2016 in India/ per capita income in 2016 in the US = 6490/58030 = 0.1120). Sengupta and Mandal (2005) use the ratio between per capita income for each of the cities considered in their study.

Step 4: Fourth, the values obtained in step (iii) are adjusted for the variation in the size of the exposed population to the pollutants by using the ratio of density of the population in the concerned Indian city to the average population density of the nine US cities of relevance for an inter-country adjustment as per the demographic data for the year 2016. Ratio of population density in India to US in 2016= 445.37/35.3283 = 12.6066.

The final marginal costs of damages to human health, visibility levels and crop losses are given in Table 5.5.

Table 5.5: Marginal damage costs from vehicular air pollutants in india

	Marginal Health Damage Costs			Marginal Visibility Damage Costs			Marginal Crop Damage Costs		
	2016 prices in ₹/gm								
Pollutants	Low Cost Estimate	High Cost Estimate	Mid point values	Low Cost Estimate	High Cost Estimate	Mid point values	Low Cost Estimate	High Cost Estimate	Mid point values
CO	0.0003	0.0034	0.0019	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
HC	0.0045	0.0500	0.0272	0.0003	0.0017	0.0010	0.0000	0.0000	0.0000
NOx	0.0548	0.8049	0.4299	0.0066	0.0379	0.0222	0.0000	0.0000	0.0000
PM10	0.4739	6.4658	3.4698	0.0138	0.1345	0.0741	0.0000	0.0000	0.0000
SOx	0.3318	3.1363	1.7340	0.0307	0.1369	0.0838	0.0000	0.0000	0.0000
HC + NOx	0.0007	0.0048	0.0028	0.0000	0.0000	0.0000	0.0066	0.0103	0.0084

Establishing the Social Costs of Carbon Dioxide (SCC): Social Costs of Carbon Dioxide equivalent (written as SC-CO_2e or SCC) is a monetary estimate of the damages to health, ecosystem, agricultural productivity and other negative contributions created per ton of carbon released[liv]. The social cost of carbon is an estimate of the monetary value of damages caused by a one-ton increase in greenhouse gas emissions in a given year. Globally relevant SCC that have been calculated by various national governments and scholars in climate economics for economic assessment of climate policies have been listed in Appendix 1.

SC-CO_2e is calculated through Impact Assessment Models (IAM). IAMs links global climate and global economy models to estimate the damages in monetary terms. The three most well known models are[lv]:

- William Nordhaus' model - Dynamic Integrated Climate and Economy (DICE) - (Yale University) - advocates for 3% discount rate
- Richard Tol's model[lvi] - Climate Framework for Uncertainty, Negotiation and Distribution (FUND) - (Sussex University) - used extensively by IPCC
- Chris Hope's model - Policy Analysis for GHG Effect (PAGE) - (Cambridge University) - used extensively by Stern Review done in 2006[lvii] and also in ExternE[lviii] project in Europe

Estimates from these three models were used to calculate the SC-CO_2e by the Interagency Working Group (IWG)[lix] group in the US government. Three discount rates have been considered: 5, 3, 2.5%. One study[lx] on social costs of vehicles in India has considered IWG's SCC values for accounting for the CO_2 costs of vehicles. However, this report first reviews key SCC estimations from various prominent models and studies (Appendix 1), followed by the identification of an SCC rang for GVR calculations.

One prominent drawback of the IAM models developed to monetise damages from every additional unit of carbon is the high level of uncertainties it contains in discounting factors, range of catastrophes included and quantified, etc. As a result, there exist a wide range of estimates, with no unanimous value to date. For instance, they have been criticised for omitting important climate impacts that are likely to become more hazardous with time, due to limited understanding of the nature of damages, data and modelling techniques[lxi]. As a consequence of the historical responsibility and matters of equity in bearing the climate impacts and role of high carbon sectors in the economy, national governments differ in the SCC values they adopt. Critics have argued for refining both the climate science and economic methods for accurately modelling the SCC.

Role of Discount Rates - Assumptions[lxii] used to set the discount rates play a critical role in estimating SCC. Higher the discount rate, lower is the valuation of the damage due to carbon dioxide for current generation, and smaller is the economic incentive to save on carbon emissions in the nearest term. A high discount rate underestimates the impacts of increased CO_2 in the atmosphere for future generations. This increases the likeliness of economic burden of global warming damages on future generations. Discount rates are decided through positive analyses (market rates) and through normative analyses (equity, ethics, political willingness, valuing damages across generations). They suffer from high dosage of uncertainty and remain a topic of debate. For instance, in response to the IWG SCC, some studies have argued that the range of discount factors from 2.5 - 5% is much too broad and should be narrower. On the other hand, even a low discount rate of 1.4 % has received high criticism as some scholars find this low rate to be stifling for economic activities, returns from which substantially benefit future generations.

It is also a common misunderstanding that SCC is the same as carbon price used for tax and emissions trading purposes (such as in Europe's Emissions Trading Scheme). In a practical and real-world carbon tax program, the price of carbon starts well below the SCC and moves in an upward trajectory until it reaches the SCC[lxiii]. However, in light of the thin faith in IAMs used to date (for instance, the three models listed above) some authors have explored replacing SCC with carbon prices. But further analyses have casted doubts whether carbon price can adequately approximate the true SCC[lxiv]. Rather, market-based cap and trade or tax programs should be used to complement the goals of setting SCC[lxv]. Some policymakers argue that excise duties on petrol and diesel consumed by vehicles can be counted towards carbon taxes. However, OECD offers some clarity: excise duties by themselves are not sufficient disincentive to control carbon intensive activities such as vehicles use. Cap and trade programs and taxes on carbon content of energy use need to be included along excise duties to create a market-based system of controlling emissions through Effective Carbon Rate[lxvi]. Social costs of CO_2 considered in the major studies are given in Table 5.6.

Table 5.6: Social costs of carbon dioxide (SCC) CO_2

PPP adjusted INR per tonne; 2016 prices	Low side estimates	Central estimate	High side estimate
IWG	₹ 242.9	₹ 850.0	₹ 1254.8
Nordhaus	₹ 441.4	₹ 1669.7	₹ 2686.8
Stern	₹ 1259.0	₹ 2548.7	₹ 3807.6

GVR uses Social Costs of CO_2 to estimate the value of damages from CO_2 emitted per km of vehicle use. A plausible range for SCC value was derived using three climate economy models: William Nordhaus's DICE model, Interagency Working Group (IWG) of the US government and Stern Review Report. Estimates from the remaining studies have been compiled in Appendix 1. Each of the SCC values, in USD per tonne, have been adjusted for inflation and PPP. Given the wide adoption of 3% discount, the central estimates SCC have been used to find the SCC range: I 850 to I 2548 per tonne of CO_2.

Calculations of Health and Environmental Costs from Vehicles: The Composite Damage Costs (CDC) are defined as the sum of 'Health Costs' and 'Environmental Costs' produced from each vehicle considered in this rating. CDC is added to the commonly-known Total Cost of Ownership, which includes fuel costs, maintenance, services, insurance for owning the vehicle to find the real costs, which in GVR is known as Real Cost Ownership (RCO), when a consumer owns a vehicle.

Composite Damage Cost of a Vehicle = ∑Health Costs + ∑Environmental Costs ———— (Eq 1)
Where all,

- ∑Health Costs = Costs from NOx + Costs from HC + Costs from CO + Costs from PM ———— (Eq 2)
  - Cost from NOx = Mass of NOx emissions (g/Km) x External Cost Factor for NOx emissions (I/gm) ———— (Eq 3)

    For NOx emissions from a diesel variant, a Conformity Factor[lxvii] of 2.4 is used to account for the discrepancy between type approval test conditions and real-world driving emissions. These factors vary by emissions norms. Authors of UK's Next Green Car Rating have partnered with organisations such as Emissions Analytics to obtain accurate emissions Real Driving Emissions[lxviii] (RDE) values through Portable Emissions Monitoring Systems (PEMS). This system is installed in the vehicle to monitor emissions while the vehicle is being driven in real world conditions as opposed to laboratory test conditions. PEMS is also used for getting accurate CO_2 emissions and fuel efficiency data. No conformity factor is used for petrol variants.

  - Cost from HC = Mass of HC emissions (g/Km) X External Cost Factor for HC emissions (I/gm) — (Eq 4)
  - Cost from CO = Mass of CO emissions (g/Km) X External Cost Factor for CO emissions (I/gm) — (Eq 5)

Outputs from (Eq 3) + (Eq 4) + (Eq 5) are added to arrive at the output for (Eq 2)

- Environmental Costs = Climate costs + Visibility costs + Losses to crops
- ∑Climate Costs = Costs from CO_2 + Costs from CH_4 ———— (Eq 6)
  - Cost from CO_2 = (Mass of CO_2-equivalent) X Social Cost for CO_2 (SCC)———— (Eq 7)

CO_2 in gm/km is derived from the unofficial fuel economy figures. For accurate representation of on-road mileage, an adjustment factor of 1.30 is used for CO_2 values.

=> Mass of CO_2 X 1.30 = Adjusted Mass of CO_2 (gm/km)

This is further multiplied by GWP of CO_2, which is 1, to obtain CO_2-equivalent.

- Cost from CH_4 = (Mass of CO_2-equivalent) X External Cost Factor for CO2 emissions ———— (Eq 8)

Mass of CH_4 emissions is nearly 20% of HC emissions[lxix]. CH_4 emissions values are multiplied with the GWP for CH_4, which is 28, to obtain CO_2-equivalent of CH_4. This CO_2-equivalent is multiplied with the SCC[lxx].

∑Visibility Costs = Costs from HC + Costs from NOx + Costs from PM ———— (Eq 9)

∑Losses to Crops Costs = Costs from HC + NOx ———— (Eq 10)

Outputs from (Eq 7) and (Eq 8) are added to obtain the output for (Eq 6)

Outputs from (Eq 6), (Eq 9) and (Eq 10) are added to obtain the Environmental Costs, which are added to (Eq 2) to find the Composite Damage Costs

Global Warming Potential (GWP) is the total energy added to the climate system by a climate forcing agent such as a greenhouse gas relative to that added by CO_2. GWP is only a default metric for normalising emissions of different gases against CO_2, and must not be treated as equivalent to increased temperature and other climate variables. The emissions values of GHGs (in gm/Km) are converted to CO_2-equivalent by multiplying with Global Warming Potential (GWP) given by the IPCC's Fifth Assessment Report[lxxi] (Arc 5). This converts GHGs into a value relative to CO_2[lxxii]. Table 5.7 shows the GWP figures.

Table 5.7: GWP of direct and indirect GHGs			
Greenhouse gas	Lifetime (years)	100-year horizon GWP100	CO_2 - equivalent
Carbon Dioxide (CO_2)	Hundreds	1	Mass of GHG * GWP
Methane (CH_4)	12	28	
Nitrous Oxide (N_2O)	114	265	

Step 4: 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. 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. ACEEE uses a gamma function[lxxiii] for converting the Environmental Damage Index (EDX) into dimensionless score that spreads between 0-100.

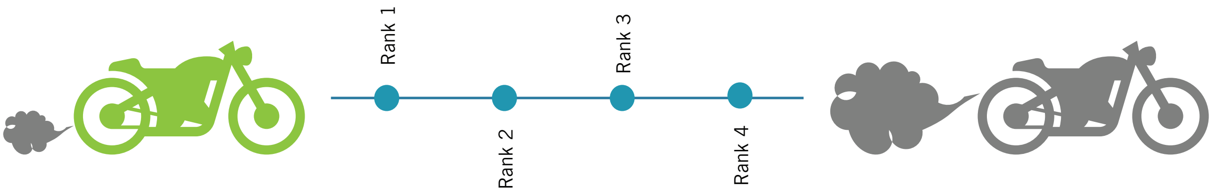


Figure 5.1: Using the 'damage score' to rank vehicles

In GVR, normalising against a reference vehicle produces two dimensionless values - environmental rating and air pollution rating - for each model (Figure 5.1). Further, these two values are added 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, lesser are its negative impacts. For both 2 and 3-wheelers, the reference vehicles[lxxiv] follow BS VI emissions norms. In the case of 2-wheelers, it has been assumed to have a fuel efficiency level of 100 km/L (approximately 25% higher fuel efficiency than maximum fuel efficiency in the pool of models selected), and 80% compliant with the BSVI emissions norms. In the case of 3-wheelers, the reference vehicle complies with BSVI norms and has mileage of 40 km/L (25% higher than the fuel efficiency level of the auto-rickshaws considered).

While undergoing the normalisation stage, the selected vehicle models are first rated against the performance of a reference vehicle, resulting in damage scores, which are used to rank the vehicles. The current sample of vehicles were manufactured in the year 2017 and follow BS IV emissions norms. Hence, the rankings of some models may alter as new vehicular technologies are rolled out next year and beyond. As a result, for ranking 2 and 3 wheelers manufactured in the year 2018 and beyond, and with the implementation of BS VI norms, the performance levels of the reference vehicle will have to be upgraded. Further analyses will be required to upgrade the reference vehicle.

Step 5: Weighting

The weightage factors assigned to various impacts reflect the regional priorities for urgent action on air pollution due burning of fossil fuels in motor vehicles and the damaging effects on human health and economic development. Therefore, a weightage factor (α) 40% of CDC was assigned to environmental effects and the remaining 60% to health impacts created due to vehicle emissions. In ACEEE's Greenercars Methodology, 70% EDX originates from GHGs and the rest from air pollutants. Belgium's Ecoscore rating has considered ecosystem impacts as well: 50% climate change, 40% air quality depletion (20% human health and 20% ecosystem impacts), and 10% noise impacts.

The five steps applied for all the 2 and 3-wheeler models are summarized in Figure 5.2. The health and environmental damage costs obtained in Step 3 were summated as the composite damage costs, that are not accounted in total cost of ownership that consumers typically estimate before purchasing a vehicle. A worked example is shown in Appendix 2 to elaborate on the calculations of: Health damage costs, Environmental costs, Composite Damage Costs, Damage Score and the Real Costs of Ownership (RCO). Chapter 5 provides the final results, followed by observations and discussions.

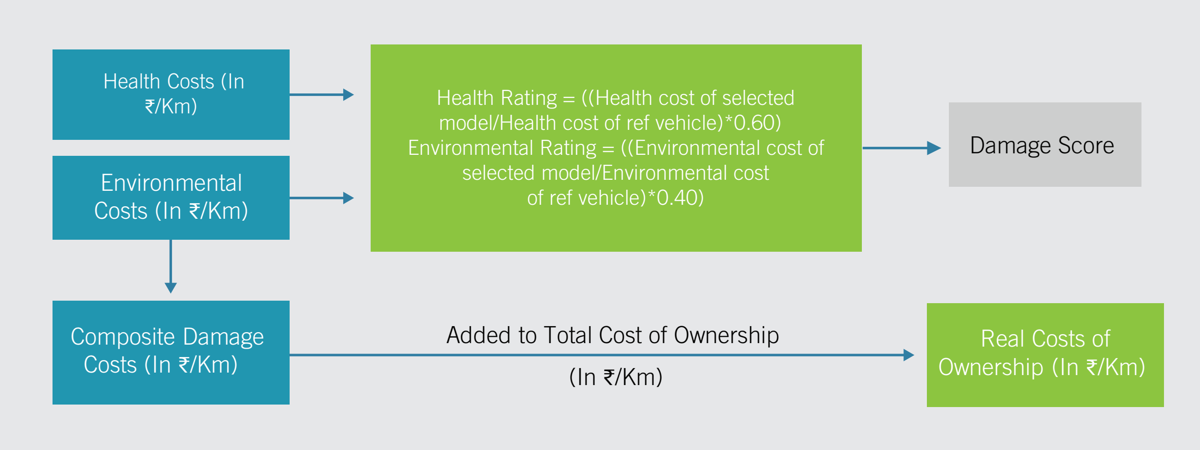


Figure 5.2: From health and environmental costs to: 1) damage score, 2) composite damage costs

CHAPTER 6

Results and Discussion

Applying the five steps of the GVR methodology, the vehicle rating has been created, where the damages from individual vehicle are normalised against a reference vehicle. This is followed by discrete results: Health damage costs, Environmental damage costs, Composite damage costs (CDC = health and environmental damage costs), Damage Score, Commonly-known Total Cost of Ownership, Real Cost of Ownership (CDC + TCO), for every vehicle in Table 6.1. The discrete results are available on the GVR portal for public consumption.

The damage scores and the vehicle ratings are presented in Figure 6.1, followed by rating as per Best by Type (Scooter/Motorcycle) in Table 6.2 and 6.3 and Best by Price brackets in Table 6.4. The presentation of results is followed by a discussion of the rating results. Although GVR only included a pilot size sample of vehicles, which is not large enough to draw correlations, but observations made have been discussed. Because the rankings of these models have been assigned based on the damage score, obtained by normalising health and environmental impacts against that of a Reference Vehicle, the ranking of these models may change in future, especially as the fleet in India begins adhering to Bharat Stage VI emissions norms in 2020. Following is an indicative presentation of the rating of 2-wheelers. In this report, the names of actual vehicle models have been replaced by dummy model names like M1, S2, *etc*.

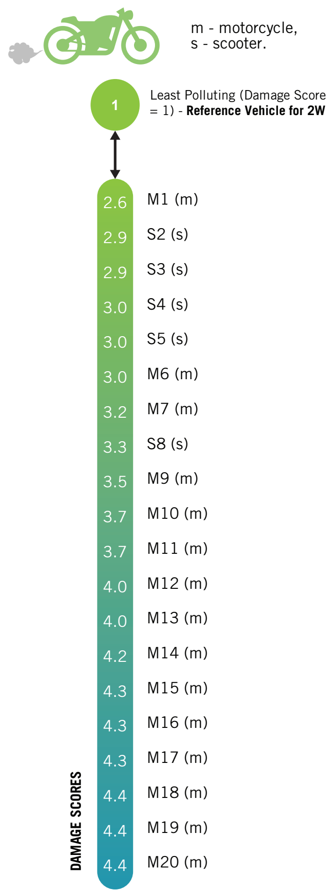


Figure 6.1: Damage scores and vehicle rankings (distance between damage scores is not to scale)

Detailed results of two-wheeler rating

Table 6.1: Overall results for 2-wheeler models

Ranking (2017)	Damage Score	Model	Type	Fuel Efficiency	Kerb Weight	Price	Health Damage Costs	Environmental Damage Costs	Composite Damage Costs (CDC)	Total cost of ownership (TCO)	Real Cost of Ownership (RCO)
		Unit		kmpl	Kg	₹	₹/km	₹/km	₹/km	₹/km	₹/km
1	2.6256	M1	Motorcycle	65	124	₹ 62032.0	₹ 0.0728	₹ 0.0866	₹ 0.1593	₹ 2.3800	₹ 2.5393
2	2.8545	S2	Scooter	64	98	₹ 50701.0	₹ 0.0817	₹ 0.0874	₹ 0.1691	₹ 2.6600	₹ 2.8291
3	2.9203	S3	Scooter	56	108	₹ 49966.0	₹ 0.0800	₹ 0.0988	₹ 0.1787	₹ 2.4700	₹ 2.6487
4	2.9763	S4	Scooter	60	108	₹ 51460.0	₹ 0.0844	₹ 0.0931	₹ 0.1776	₹ 2.4600	₹ 2.6376
5	2.9944	S5	Scooter	51	110	₹ 49900.0	₹ 0.0796	₹ 0.1072	₹ 0.1869	₹ 1.9000	₹ 2.0869
6	3.0440	M6	Motorcycle	55	125	₹ 56847.0	₹ 0.0841	₹ 0.1009	₹ 0.1850	₹ 2.0700	₹ 2.2550
7	3.2494	M7	Scooter	63	101	₹ 46104.0	₹ 0.0965	₹ 0.0906	₹ 0.1871	₹ 2.1800	₹ 2.3671
8	3.3210	S8	Scooter	45	116	₹ 47250.0	₹ 0.0875	₹ 0.1210	₹ 0.2085	₹ 2.3600	₹ 2.5685
9	3.5322	M9	Motorcycle	65	120	₹ 56429.0	₹ 0.1083	₹ 0.0896	₹ 0.1979	₹ 2.3300	₹ 2.5279
10	3.6950	M10	Motorcycle	84	115	₹ 51796.0	₹ 0.1217	₹ 0.0723	₹ 0.1940	₹ 2.0100	₹ 2.2040
11	3.7020	M11	Motorcycle	83	110	₹ 47506.0	₹ 0.1217	₹ 0.0731	₹ 0.1947	₹ 1.8900	₹ 2.0847
12	3.9769	M12	Motorcycle	65	143	₹ 81230.0	₹ 0.1253	₹ 0.0923	₹ 0.2176	₹ 2.3600	₹ 2.5776
13	4.0358	M13	Motorcycle	75	115	₹ 54080.0	₹ 0.1322	₹ 0.0807	₹ 0.2129	₹ 2.0300	₹ 2.2429

Table 6.1: Overall results for 2-wheeler models

Ranking (2017)	Damage Score	Model	Type	Fuel Efficiency	Kerb Weight	Price	Health Damage Costs	Environmental Damage Costs	Composite Damage Costs (CDC)	Total cost of ownership (TCO)	Real Cost of Ownership (RCO)
		Unit		kmpl	Kg	₹	₹/km	₹/km	₹/km	₹/km	₹/km
14	4.2416	M14	Motorcycle	75	121	₹ 57190.0	₹ 0.1426	₹ 0.0756	₹ 0.2181	₹ 2.0600	₹ 2.2781
15	4.2604	M15	Motorcycle	38	155	₹ 94683.0	₹ 0.1168	₹ 0.1437	₹ 0.2605	₹ 3.0800	₹ 3.3405
16	4.2897	M16	Motorcycle	81	109	₹ 48520.0	₹ 0.1426	₹ 0.0806	₹ 0.2231	₹ 1.9800	₹ 2.2031
17	4.3183	M17	Motorcycle	40	140	₹ 87737.0	₹ 0.1213	₹ 0.1381	₹ 0.2594	₹ 3.0500	₹ 3.3094
18	4.3605	M18	Motorcycle	50	139	₹ 65594.0	₹ 0.1322	₹ 0.1145	₹ 0.2467	₹ 2.5700	₹ 2.8167
19	4.3738	M19	Motorcycle	45	148	₹ 80435.0	₹ 0.1276	₹ 0.1277	₹ 0.2553	₹ 2.9900	₹ 3.2453
20	4.4235	M20	Motorcycle	37	187	₹ 135378.0	₹ 0.1212	₹ 0.1494	₹ 0.2706	₹ 3.8100	₹ 4.0806

Notes:

Prices are ex-showroom in Delhi. Variation of 10-20% expected for prices in other cities.

In TCO, depreciation, maintenance and service, finance, insurance, fuel costs have been accounted for a period of 5 years. It was assumed that a two wheeler runs 2000 kms a month. Road taxes are not included. As per standard market practice, it was assumed that two wheelers are financed for 85% of the retail price through a five year loan at 10.5% annual interest rate. It was also assumed that fuel costs rise at 1% annually.

Observations and discussion

Because of 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 illnesses and increased medical expenditures, PM emissions were found to have the highest marginal damage costs out of all of the criteria pollutants (₹0.5 - ₹6.50 per gram). But due to absence of an official type-approval PM data in Form 22, its health damage costs have 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.

Health and environmental damage costs 6 - 10% of total cost of ownership

It can be inferred from Table 6.1 that on an average composite damage costs, sum of health and environmental damage costs, stand at 6 - 10% of the TCO. Examples provide clear evidence. For instance, M1, placed 1st in the Green Vehicle Rating. The Composite Damage Cost (CDC) per km for this model is ₹0.1593, which will lead to monthly CDC of approximately ₹320, and will add an annual CDC of ₹3800. Because vehicle emissions control systems deteriorate with age[lxxv] and use[lxxvi] resulting in increased level of emissions, it is most likely that the composite damage costs will increase over time.

While it is expected that a vehicle with a higher Damage Score will have a higher CDC than a vehicle with lower damage score. However, comparison of some vehicles in Table 6.1 reflect otherwise. Take for instance, between M17 (ranked 17th) and M18 (ranked 18th), the CDC of M17 is higher than that of M18 because the former emits lesser air pollutants, which carries 60% weight in the damage score. M17 is less fuel efficient, resulting in higher environmental costs. Since environmental costs carry only 40% of the weight in the damage score, M17 has a higher CDC but a smaller damage score than M18 (Figure 6.2).

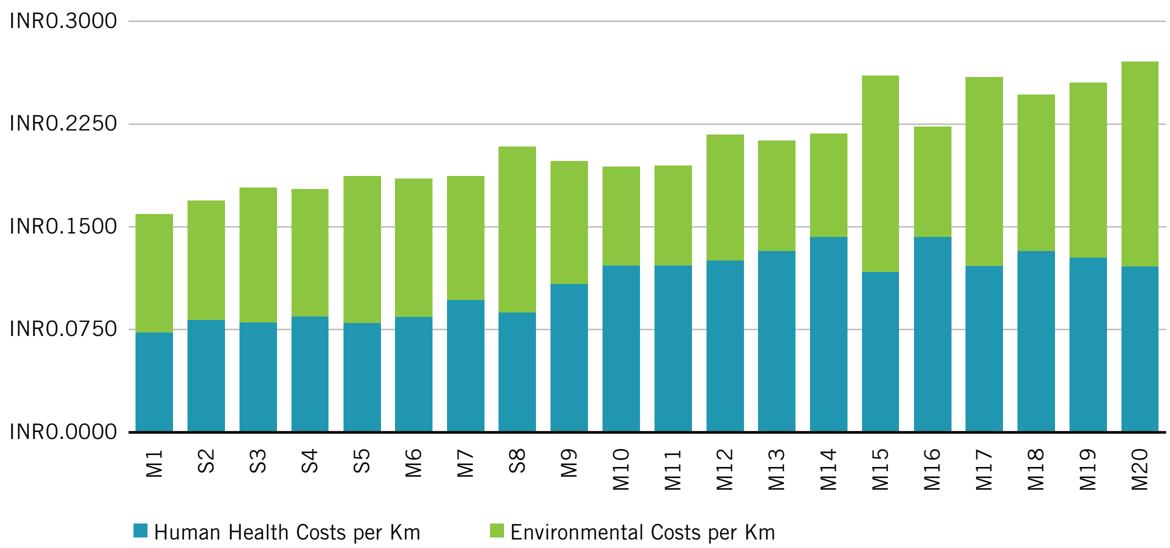


Figure 6.2: Health and environmental costs of rank 1 to 20 of two wheelers

Bridging price disparities between high upfront costs and clean vehicle technologies

Due to high retail price and fuel costs of the two wheelers, the Real Costs of Ownership (RCO), sum of TCO and CDC, is in many cases lower for highly polluting models than for cleaner ones (Figure 6.3 and Table 6.4). Take for instance, M12 (ranked 12th) and M13 (ranked 13th). Higher TCO and lower mileage increase the cost of ownership of M12 and make M13, a comparatively more polluting model, less expensive to own. Mitigating the inconsistencies between the cost of ownership and damage costs levied on public health and environmental resources has policy implications. It indicates that the costs of emission controlling technologies in vehicles is not being internalised in the retail price of the vehicle, which is a dominant factor in costs of ownership. As a step forward in that direction, GVR, through the rating of vehicles and accounting of social costs on public health and environment, allows consumers to get thorough information of the unaccounted costs, beyond the vehicle price and maintenance, finance, depreciation and fuel.

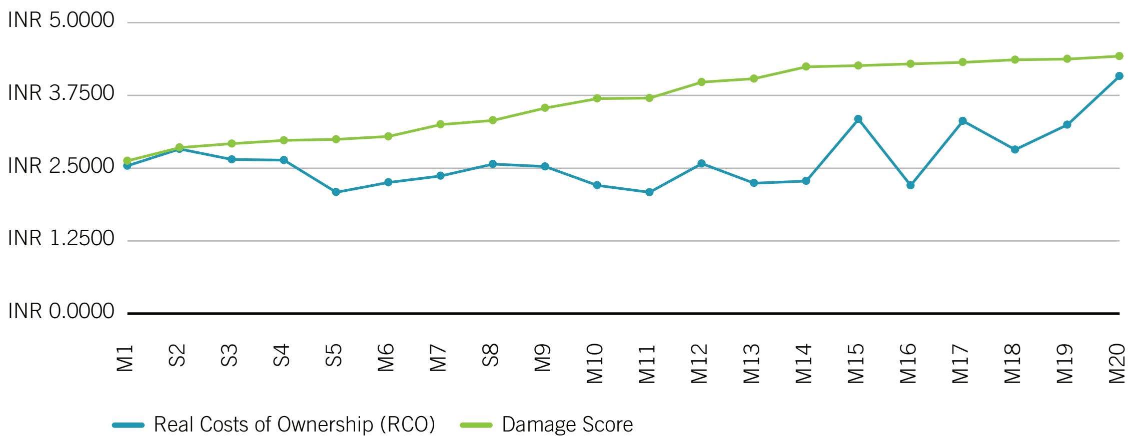


Figure 6.3: Damage scores and real-costs of ownership for rank 1 to 20 of two wheelers

High fuel efficiency, yet high air pollution costs

Observations made by analysing the final ratings also reassert[lxxvii] that to curb negative externalities due to vehicular emissions that burden public health and worsen climate change, only measuring fuel consumption or the CO_2 released from the tail pipe is insufficient. Take for example, the motorcycle, M11 (placed 11th). Gains from mitigation of tail pipe carbon emissions due to a high mileage of 83 kmpl are outweighed due to losses from high levels of air pollutants released and the resulting health costs for consumers. While the models rated in GVR are only petrol based, but the paradox of high fuel efficiency and high air pollution costs is even more evident in diesel vehicles, which are well-known for high fuel economy, however, emit very high levels of gaseous pollutants.

As shown in Table 6.2 and 6.3, except for two motorcycles, M1 (placed 1st) and M6 (placed 6th), scooters are less polluting and score lower on damages than motorcycles.

In many cases the health damage costs outweigh the gains from high fuel efficiency (Figure 6.2), as evident from a comparison of health and environmental costs of M9 (ranked 9th) and M10 (ranked 10th). In the case of M16, while the fuel efficiency is on the higher end (81 kmpl), the health damage costs are the highest within the pool of two wheelers considered, resulting in a higher damage score and a lower rating.

The two wheeler segment is a highlight price sensitive market, where many consumers survey the market with a price bracket in mind. Hence, in Table 6.4, low to high performers have been identified as per various price brackets, for motorcycles and for scooters.

Takeaways

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 emission control devices, and contextual (non-vehicle technology) factors such as fuel quality, and driving conditions that together determine the quantity of exhaust emissions released. Further the monetary losses from environmental externalities due to emissions is 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 in their purchase decisions and progress from being aware to taking action. Comparative rating, given in Table 6.1 and Figure 6.1, makes high performers identifiable to both policymakers and consumers, and auto making businesses. The damage cost method used in GVR, although nascent in comparison to the analyses performed in other data proficient countries, makes the case that evaluating the economics of externalities due to energy-related pollution from transport sector is fundamental to understand the cost worthiness of regulatory investments in vehicle air pollution control and forming economically efficient disincentives for vehicle segments with high air pollution costs and warming effect from carbon emissions.

Table 6.2: Rating by two wheeler type - Motorcycles

Model Name	Damage Score	Green Vehicle Rating (GVR)
M1	2.6256	1
M6	3.0440	6
M9	3.5322	9
M10	3.6950	10
M11	3.7020	11
M12	3.9769	12
M13	4.0358	13
M14	4.2416	14
M15	4.2604	15
M16	4.2897	16
M17	4.3183	17
M18	4.3605	18
M19	4.3738	19
M20	4.4235	20

Table 6.3: Rating by two wheeler type - Scooters

Model Name	Damage Score	Green Vehicle Rating (GVR)
S2	2.8545	2
S3	2.9203	3
S4	2.9763	4
S5	2.9944	5
S7	3.2494	7
S8	3.3210	8

Price range of Vehicle ('000)	Real Costs of Ownership (RCO) = TCO + CDC per Km	Model name	Type	Damage Score	Ranking
Table 6.4: Green vehicle rating based on price brackets					
45-50	₹ 2.0847	M11	Motorcycle	3.7020	11
	₹ 2.2031	M16	Motorcycle	4.2897	16
50-55	₹ 2.2550	M6	Motorcycle	3.0440	6
	₹ 2.2040	M10	Motorcycle	3.6950	10
	₹ 2.2429	M14	Motorcycle	4.0358	14
55-60	₹ 2.5279	M9	Motorcycle	3.5322	9
	₹ 2.2781	M12	Motorcycle	4.2416	12
60-65	₹ 2.5393	M1	Motorcycle	2.6256	1
65-70	₹ 2.8167	M18	Motorcycle	4.3605	18
	₹ 2.5776	M13	Motorcycle	3.9769	13
80-85	₹ 3.2453	M19	Motorcycle	4.3738	19
85-90	₹ 3.3094	M17	Motorcycle	4.3183	17
90-95	₹ 3.3405	M15	Motorcycle	4.2604	15
100+	₹ 4.0806	M20	Motorcycle	4.4235	20
45-50	₹ 2.6487	S3	Scooter	2.9203	3
	₹ 2.0869	S5	Scooter	2.9944	5
	₹ 2.3671	S7	Scooter	3.2494	7
	₹ 2.5685	S8	Scooter	3.3210	8
50-55	₹ 2.8291	S2	Scooter	2.8545	2
	₹ 2.6376	S4	Scooter	2.9763	4

Overall three-wheeler rating

In the two auto rickshaws compared, LPG variant is less damaging than the diesel variant (Table 6.5). This is predominantly because of the high health costs from the diesel variant whose particulate levels were reported on Form 22 and have been included in these costs. The total costs of ownership for auto rickshaws have been obtained from three wheeler surveys done by other organisations[lxxviii].

Table 6.5: Ranking and RCO of passenger 3-wheelers

Ranking (2017)	Damage Score (rated against reference vehicle)	Model Name	Type	Human Health Costs per Km	Environmental Costs per Km	Composite Damage Costs (CDC) per Km	Total cost of ownership* (TCO) per Km	Real Costs of Ownership (RCO) per Km
1	1.7663	A1	Passenger Autorickshaw	₹ 0.0018	₹ 0.2248	₹ 0.2267	₹ 2.8000	₹ 3.0267
2	1.9624	A2		₹ 0.0892	₹ 0.1994	₹ 0.2886	₹ 2.8000	₹ 3.0886

CHAPTER 7

Driving the wheels of change forward: Future work and policy recommendations

This report stands at the premise that public information will enable consumers to account for the energy and environment burdens when purchasing vehicles. This public scrutiny will, in theory, grow the demand for vehicles that are less polluting and have lesser greenhouse gas impacts, resulting in auto makers to transition to less polluting vehicle technologies and modify vehicle characteristics.

Use of public information program for controlling and managing vehicle emissions and energy use is urgently needed in India. To create a robust and effective information strategy, lessons drawn while creating the Green Vehicle Rating offers insights into areas for future research, followed by a set of policy recommendations to complement the goals of the vehicle rating and other information strategies. In addition, readers are advised to review the takeaways from rating results that have been detailed at the end of Chapter 6.

Developing effective regulatory mechanisms to nudge the auto sector towards a cleaner future

The current GVR program is a steppingstone to bring a range of regulatory reforms as described below.

- As GVR reveals the *"cost"* of the impact of use of different models of two and three wheelers on human health and the environment in the country and ranks the models according to their damage scores, the policymakers can leverage these insights to introduce a *"feebate"* system based on the *"polluter pays"* principle. In such a system, higher taxes are imposed on more polluting vehicle models and the revenue collected can be used to provide incentives to cleaner technologies and fund R&D activities. The estimated health and environmental damage costs for individual vehicle models can also be used as a basis to set the tax level for the polluting models. On similar line, the concerned authority may consider waiving the registration fee for greener variants of vehicles.

Such *"feebate"* or *"tax and credit"* system is already prevalent in numerous countries and regions around the world, with a range of stringency and varying success. These policies differ in factors such as efficiency criterion, functional form, and whether they are self-financing, depending on each program's political conditions and goals. Several European countries -including Denmark, France, the Netherlands, and Norway – have observed clear shifts in car purchasing decisions toward lower emission vehicles since implementing feebate-like policies over the past decade.

NITI Aayog in partnership with the Rocky Mountain Institute (RMI) has carried out an exploratory study on the potential for the design and implementation of a national feebate policy to drive vehicle efficiency in India.

- GVR program can be leveraged by the concerned authority to introduce a Star labelling program for two and three wheelers based on the pollutant emissions profile and fuel economy of the vehicle models. This would require setting criteria for grading the vehicles under different Star levels and also, there might be a need categorize the two wheelers as per their engine capacities. Already a successful Standards & Labeling Program for certain appliances is effective in the country since year 2006, administered by BEE. The latter is currently considering to introduce Standards & Labeling Program for passenger vehicles.
- There are suggestions from experts that the GVR program can be extended to develop a dedicated Corporate Average Fuel Economy (CAFE) standards for two and three wheelers. Currently, BEE has set CAFE standard for passenger cars. Hence, similar standard can be stipulated for two and three wheelers. This would require further deliberations on setting the targets.

Pollution data disclosure in Form 22: A welcome move, but wide gaps need to be plugged-in

- First and foremost, particulate matter data (PM2.5 and 10) needs to be declared on Form 22, irrespective vehicle fuel type. Particulate matter from vehicle exhausts has serious health and economic burden which needs to be urgently conveyed to the consumer for accounting in their purchase decisions. Currently, it is only declared for diesel vehicles. This is a loss since two wheelers primarily run on petrol in India and despite their majority share in India's fleet and oil consumption, consumers have no information on particulates released from the tail pipes.
- Getting consumers to make Form 22 integral to their purchase processes requires a concerted effort by regulators. Adequate directives need to be issued to auto manufacturers, who should direct the dealers for sharing the Form 22 with consumers. Currently, auto dealers generally are unaware of the relevance of Form 22 and/or are reluctant to share its details with consumers. GVR fills this gap with an consumer oriented video to sensitize motorists on the role of Form 22, processing its data to make it available to consumers in a usable format and by making Form 22 of the twenty two top selling models publicly accessible on its webpages. But in light of the large population of these vehicles and the number of models produced annually, regulatory support is fundamental for helping consumers understand why and how to use this form.
- For amplifying the use of type approval data listed on Form 22, the pollutant data for new models manufactured every year should be collated and listed on a public website. This will omit the dependency of procuring the Form 22 from auto dealers, and will allow consumers to check and compare vehicle emission for a wide range of models on one platform, while surveying the market for their purchase. In the near term, a public repository of Form 22 will directly benefit consumers and multiple stakeholders, such as researchers and policymakers in the process of charting national action plans on air quality and climate change (MoEFCC, MoPNG), and auto businesses. In the medium to long range, dynamic websites[lxxix] should be developed on which consumers can sort vehicles as per manufacturer, fuel, engine size, speed and compare their emissions levels. Type approval testing takes place at government authorised labs such as ARAI, ICAT, VRDE, which currently do not have the legal provisions to share the type approval data of vehicles with anyone other than the manufacturing company.

Making CO_2 type approval data publicly available

Unlike the pollutants data disclosed on Form 22, type approval data for carbon dioxide emissions is not disclosed, nor is there any government mandated disclosure of fuel efficiency levels of a vehicle. Many unofficial figures are available in the market. However, they do not confirm with the on-road conditions, and there remains a significant difference in mileage in city and highway (or freeway) conditions. The lack of information on CO_2 emitted from vehicles, and the greenhouse gas emissions produced from vehicle use ratifies the need for making official fuel efficiency scores public. While passenger cars have a CAFE standard, two and three wheelers, despite being major oil consumers, are not subjected to any fuel consumption standards. Hence, disclosure of CO_2 type approval data is recommended. It will not only aid in compositely analysing the undesirable effects of GHGs and air pollutants from vehicle tail pipes, but will inform consumer decisions with reliable estimates of fuel economy levels.

Studying the costs of externalities from energy-related pollution impacts in India

Measuring the costs of negative externalities produced from fuel combustion in vehicles - burdens on public health, air quality, ecosystem damage, greenhouse gas emissions - is fundamental to investing in policies and strategies that are prioritised[lxxx], economically efficient pricing for use and ownership of motor vehicles (for instance, promoting less polluting vehicle technologies through tax differentials), understanding the long range impacts of upgradation and regulatory amendments (for instance, the costs and benefits from reduced health and environmental burden from upgradation to BS VI).

Other major vehicle markets such as Europe and the United States have been using economic evaluation of environmental externalities, with projects such as ExternE that commenced with a 3 year collaborative study by European Commission and US Department of Energy[lxxxi], and a series of 21 reports on social costs of transportation by Institute of Transportation Studies, UC Davis, that was supported by the government bodies in the United States. The topic of accounting for external costs in policy analysis gained attention of policymakers since early 1990s. These projects have use damage functions and assessed the external costs of impacts ranging from environmental, public health, global warming, energy security. These projects are extensive and highly dependent on large volumes of primary data, sophisticated modelings and experts in pertinent areas.

It is recommended that a counterpart of studies be commissioned by policymakers in India to calculate external costs of air pollutants and GHGs in India. Outcomes produced include: marginal external cost factors (such as those estimated in this report for various pollutants in ₹/kg terms), total costs and expected benefits of policy measures. This will especially benefit the National Clean Air Program of MoEFCC by helping set up quantified ambient pollution standards, deciding the size of investment for an area of intervention as per the negative contribution of the sector (power plants, transportation, agriculture), evaluation of investment to be made and tracking the benefits accrued from riddance of serious health and economic burdens. Given the diversity of expertise needed and complexity in modeling required, it is recommended that the study be steered with a joint effort from epidemiologists, energy and climate economists, climate and environmental scientists and air pollution experts, and oil and automobile sector experts.

Towards electric vehicles, with a life cycle approach

To understand the emissions released in the production of a vehicle and the fuel production and distribution processes, conducting a Life Cycle Analysis (LCA) for accounting GHG and criteria pollutant released will be highly beneficial. Such accounting has been done in other international ratings. LCA approach takes into account direct (in-use) and indirect (upstream and downstream) emissions of criteria pollutants and GHGs, followed by the damage cost method used in GVR. A schematic[lxxxii] of the value chain in vehicle manufacturing and use is presented in Figure 7.1. While electric vehicles have zero tail pipe emissions, their manufacturing process, production of electricity and disposal (mainly due to the battery) result in indirect emissions. Such analysis will help consumers see how clean their electric vehicle is. However, large amounts of reliable data on emissions from point sources is needed to accomplish this approach.

Assessing the level of emissions and the costs of externalities produced from emissions released over the lifetime of a vehicle will help policymakers compare the impacts and costs of electric in comparison to petrol and diesel vehicles. This will provide them with concrete indications on the most emission-intensive stages in the lifecycle of a vehicle, and invest in policies at the stages with high returns on emissions saving with least investment. For instance, while the administrative costs of regulations to alter motorist's driving behaviour may be prohibitively high, but policymakers can look for alternatives - such as incentives at preceding upstream stages of fuel refining and manufacturing of less polluting vehicles.

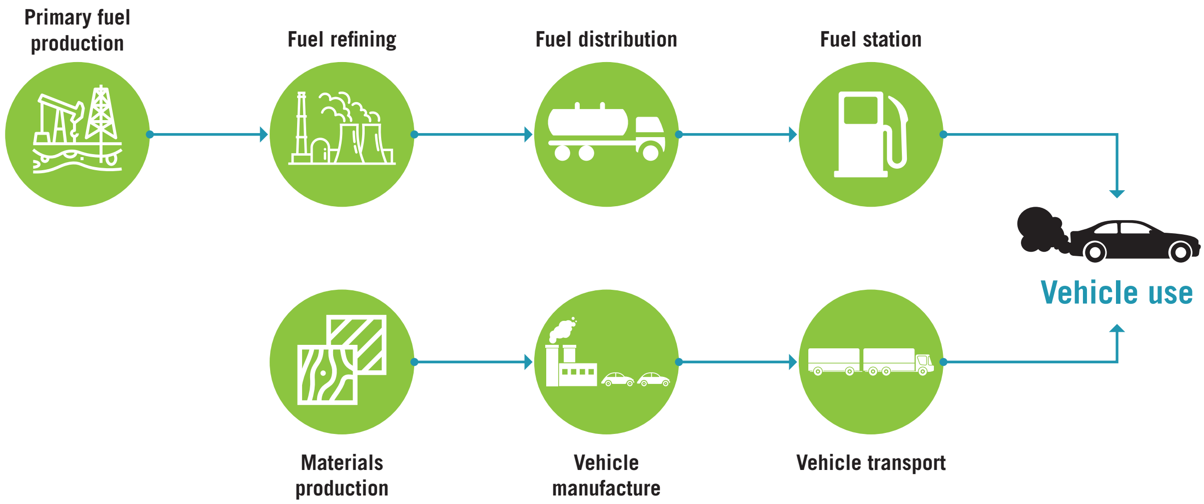


Figure 7.1: Value chain of vehicle manufacturing and use

Appendix 1

Values from existing studies and models on Social Costs of CO_2 (SCC)

Source /Author		SCC at High discount	SCC at Central discount	SCC at Least discount
	Points to Remember: SCC are globally relevant, unless otherwise notes below SCC stands for Social Cost of CO_2 in the information given below. Oftentimes, authors of climate-economy models calculate Social Costs of Carbon, which can be divided by (44/12=3.67) to arrive at Social Cost of CO_2 (SCC); All prices are for 2016, unless noted; Median values at various discount rates			
Interagency Working Group (IWG) on Social Cost of Greenhouse Gases, United States Government Executive Order 12866 - in 2007$ per tonne	Relevant globally	12.000	42.000	62.000
Discount rate (s)		5.00%	3.00%	2.50%
Adjusting for inflation (2007$ to 2016$)		13.920	48.720	71.920
(PPP adjusted) - INR per tonne		**242.862**	**850.018**	**1254.788**
NOTES: IWG's estimates have been derived through 3 climate-economy models: DICE, PAGE and FUND (described in the write-up above); based on this, ACEEE uses $0.0237 per Kg of CO_2e. https://www.epa.gov/sites/production/files/2016-12/documents/sc_co2_tsd_august_2016.pdf				
William Nordhaus - Author of DICE model	Relevant globally			
Discount rate (s)		5.00%	3.00%	2.50%
DICE (version 2016) (in 2010 $) - Global SC of Carbon		23.000	87.000	140.000
Adjusting for inflation (2010$ to 2016$)		25.300	95.700	154.000
SC - CO_2		6.894	26.076	41.962
(PPP adjusted) INR per tonne		**120.275**	**454.953**	**732.108**
NOTES: advocates for a 3% discount rate				

Source /Author		SCC at High discount		SCC at Central discount		SCC at Least discount	
Stern Review: The Economics of Climate Change (in USD per tonne C)		41.000		83.000		124.000	
Discount rate	Relevant globally	between 0.1% - 1.4%					
Adjusting for inflation (2006$ to 2016$)		72.160		146.080		218.240	
SC - CO_2		19.662		39.804		59.466	
(PPP adjusted) INR per tonne		343.045		694.457		1037.502	
NOTES: Discount rate is near-zero; http://mudancasclimaticas.cptec.inpe.br/~rmclima/pdfs/destaques/sternreview_report_complete.pdf							
Shindell, Drew T. (2013): The social cost of atmospheric release, Economics Discussion Papers, No. 2013-56 - in USD per tonne		6.000	26.000	17.000	71.000	70.000	250.000
Adjusting for inflation (2007$ to 2016$)	Relevant globally	6.960	30.160	19.720	82.360	81.200	290.000
Discount rate		5.00%		3.00%		1.40%	
(PPP adjusted) INR per tonne		121.431	526.202	344.055	1436.935	1416.696	5059.630
		323.816		**890.495**		**3238.163**	
NOTES: Fair bit of uncertainty ~50% in climate valuations							
Tol, Richard (2005) (2005$ assumption based on year of publishing)		50.000					
Adjusting for inflation (2005$ to 2016$)	Relevant globally	61.500					
(PPP adjusted) INR per tonne		**1072.991**					
Discount rate		1%[3]					
NOTES: Main conclusion: Marginal damage cost of carbon dioxide is likely to be substantially smaller than $50 per tonne. http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.175.5846&rep=rep1&type=pdf							
ExternE - Maibach et al (2008) - in € per tonne		17.000		40.000		70.000	
Discount rates	Relevant for EU member states;	3%		1%		0%	
in Intl $/tonne		**12.801**		**30.120**		**52.710**	
NOTES: ExternE uses a combination of PAGE and Open Framework models							

3 As per the author, a stringent discount rate of 1%, while morally preferable, is out of line with the conventional discount rates used for SCC by various governments (which is between 3-5%). Hence, when a higher discount will be applied, SCC will decrease.

Appendix 2

This section comprises worked examples of calculation performed to obtain the health and environmental costs, damage score against a reference vehicle. First, calculations for the reference vehicle (for two wheelers) is produced, followed by a selected model (M13).

Reference Vehicle (2-wheelers)— fuel economy: 100 Km/L (assumed)

Reference Vehicle - fuel economy 100 Km/L and BS VI emissions norms	
Total Environmental Cost (in ₹/Km)	₹ 0.0416
Total Human Health Costs	₹ 0.0243

Air Pollutant	Mass (gm/Km)	Marginal Health Costs (₹/gm)		Health Costs (₹/Km)	
Carbon Monoxide (CO)	0.80	₹ 0.0003	₹ 0.0034	₹ 0.0003	₹ 0.0028
Hydrocarbons (HC)	0.08	₹ 0.0045	₹ 0.0500	₹ 0.0004	₹ 0.0040
Nitrogen Oxides (NOx)	0.048	₹ 0.0548	₹ 0.8049	₹ 0.0026	₹ 0.0386
				₹ 0.0033	₹ 0.0454
Total Health Costs from Reference Vehicle				₹ 0.0243	

GHG	Mass (gm/Km)	Mass of CO_2-equivalent (gm/Km)	Social Cost for CO_2-equivalent (₹/gm)		GHG Costs (₹/Km)	
Carbon Dioxide (CO_2)	22.9482	22.9482	0.0009	0.0025	0.0195	0.0585
Methane (CH_4)	0.0160	0.4480			0.0004	0.0011
Total		23.3962			0.0199	0.0596
Climate costs					0.0398	
Total Environmental Cost from Reference Vehicle (in ₹/Km)					0.0416	

Air Pollutant	Mass (gm/Km)	Marginal Visibility Costs		Visibility Costs		Marginal Costs of Crop Losses		Costs from Crops Losses	
Carbon Monoxide (CO)	0.80	—	—	—	—				
Hydrocarbons (HC)	0.08	₹ 0.0003	₹ 0.0017	₹ 0.00003	₹ 0.0001	0.0066	0.0103	0.0008	₹ 0.0006
Nitrogen Oxides (NOx)	0.048	₹ 0.0066	₹ 0.0379	₹ 0.0003	₹ 0.0018				
				₹ 0.0003	₹ 0.0020				
				₹ 0.0012				₹ 0.00073	

M13 (Fuel type: petrol, fuel economy: 81 Km/L, Ex showroom price: ₹ 48520)					
HUMAN HEALTH COSTS					
Air Pollutant	Mass (gm/Km)	Marginal Health Damage Cost (₹/gm)		Health Costs (₹/Km)	
CO	0.2550	₹ 0.0003	₹ 0.0034	₹ 0.0001	₹ 0.0009
HC	0.1660	₹ 0.0045	₹ 0.0500	₹ 0.0007	₹ 0.0083
NOx	0.3200	₹ 0.0548	₹ 0.8049	₹ 0.0175	₹ 0.2576
PM	—	0.4739	6.4658		
SOx *	—	0.3318	3.1363		
HC + NOx	0.4860	0.0007	0.0048		
				0.0184	0.2668
Total Human Health Costs (₹/Km)				₹ 0.1426	
Health rating (= (Health costs/Health costs for ref vehicle)*0.60)				3.5157	

Environmental costs 1										
Air Pollutant	Mass [4](gm/Km)	Marginal Visibility costs		Visibility Costs		Marginal Crop loss Costs		Crop loss costs	
CO	0.2550	—	—	—	—	—	—	—	—
HC	0.1660	0.0003	0.0017	₹ 0.0001	₹ 0.0003	—	—	—	—
NOx	0.3200	0.0066	0.0379	₹ 0.0021	₹ 0.0121	—	—	—	—
PM	—	0.0138	0.1345			—	—		
SOx *	—	0.0307	0.1369			—	—		
HC + NOx	0.4860	—	—			0.0066	0.0103	0.0032	0.0050
				0.0022	0.0124			0.0032	0.0050
				0.0073				0.0041	

Environmental costs						
GHG	Mass of GHG (gm/Km)	Mass of CO_2-equivalent (gm/Km)	Social Cost for CO_2 (I/gm)		Climate Costs (I/Km)	
Carbon Dioxide (CO_2)	39.7768	39.7768	0.0009	0.0025	0.0338	0.1014
Methane (CH_4)	0.0332	0.9296			0.0008	0.0024
					0.0346	0.1037
	Climate Costs				0.0692	
	Visibility Costs				0.0073	
	Crop Losses				0.0041	
	Total Environmental Costs				0.0806	
	Environmental rating (= (Environmental costs/ Environmental costs for ref vehicle)*0.40)				0.7741	

Final scores for M13	
Green Vehicle Rating (GVR)	
Human Health Costs per Km	₹ 0.1426
Environmental Costs per Km	₹ 0.0806
Composite Damage Costs (CDC) per Km	₹ 0.2231
Total cost of ownership (TCO) per Km	₹ 1.8200
Real Costs of Ownership (RCO) = TCO + CDC per Km	₹ 2.0431
Damage Score = Health rating + Environmental rating	4.2897

4 These values have been sourced from Form 22 where manufacturers are required to declare the emissions values for each vehicle model, as mandated by the Ministry of Road Transport and Highways (MoRTH).

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