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Methodological approach to obtain key attributes affecting the adoption of plug-in hybrid electric vehicle

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ABSTRACT

The present study demonstrates a methodological approach to prioritize a key set of attributes influencing consumer perception towards Plug-in Hybrid Electric Vehicles (PHEVs) in a typical Indian context. Based on the literature search, an exclusive set of 22 attributes influencing PHEV adoption were selected and conventional car owners' perception towards these attributes were collected from two Indian megacities, namely Delhi and Kolkata. Initially, Kruskal-Wallis H-test was used to investigate heterogeneity in consumer perception towards PHEV-related attributes across different population subgroups. The heterogeneity study revealed a significant difference in perception for several attributes across the two cities. Subsequently, Exploratory Factor Analysis (EFA) was used to identify a set of latent factors influencing PHEV choice for both cities. For ranking of attributes within each latent factor, Grey Relation Analysis (GRA), was employed. Based on the EFA and GRA results, purchase cost, safety, air conditioning, battery warranty, public charging availability, battery recharging time, and tailpipe emission are identified as key attributes affecting PHEV adoption. Such findings could guide the car manufacturers and the government to lay an added emphasis on the priority attributes to enhance the appeal of PHEV as a mode among Indian consumers.

1. Introduction

Global warming caused by greenhouse gas (GHG) (especially CO_2) emissions, and the subsequent climate change has become the world's major issue (Bera and Maitra, 2019). The transportation sector has been constantly cited as a significant contributor through human intervention to climate change (Lévay et al., 2017). According to International Energy Agency (IEA), the transportation sector solely contributed to 24 % of global CO_2 emissions from fuel combustion (IEA, 2020). Specifically, road transport is a primary contributor, with passenger cars adding up a significant proportion of vehicular emissions (Choudhary et al., 2021). In a developing country such as India, economic growth is resulting in high rates of rural-to-urban migration and rapid urbanization (Bera and Maitra, 2021a). The increase in urban population together with their higher income and modern standard of living has led to the rising trends of passenger car ownership in urban areas (Bera and Maitra, 2023). As a result, India's per-capita car ownership per 1000 persons increased from 13 in 2011 to 22 in 2017, with a predicted growth to 170 by 2040. (IEA Statistics, 2017; Ministry of Road Transport and Highways (MoRTH), 2021). A study done by Sharma and Chandel (2020) conclude that a car emits 604 mg of CO, 139 mg of HC, 178 mg of NOx, 144 g of CO_2, and 4 mg of PM2.5 per km travel. The toxic exhaust emissions released into the atmosphere substantially deteriorate the urban air quality and are subsequently accountable for health concerns among urban residents (Bera and Maitra, 2022). Apart from the negative environmental implications, importing crude oil to power the increasing fleet of passenger cars poses a substantial threat to economic growth and future energy security (Bera and Maitra, 2021b). Therefore, to address the issues related to rising air pollution and future energy security, there is a need to replace the use of conventional fossil-fuel based cars with innovative and low-carbon emitting alternatives such as electric vehicles to create a sustainable urban ecosystem (Bhan et al., 2020).

EVs introduced into the global market are broadly classified into three categories, namely Hybrid EV (HEV), Plug-in Hybrid EV (PHEV), and Battery EV (BEV) (Egbue and Long, 2012). Each category of EVs possesses its own set of benefits and drawbacks as compared to CVs. For a typical Indian scenario, this study is conducted considering PHEV. A PHEV uses battery pack to power an electric motor, and conventional fuel, such as gasoline, to power an internal combustion engine (ICE) for vehicle propulsion (Markel and Simpson, 2007). The battery can be

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recharged externally by plugging a charging cable into an external electric power source, and internally by internal combustion engine or through regenerative braking (Zoepf et al., 2013). The battery pack allows the vehicle to operate predominantly on electricity during short trips, offering high fuel economy to consumers (Axsen and Kurani, 2010). For longer trips, PHEV uses conventional fuel from its onboard tank to provide a driving range similar to that of CVs. PHEV produces zero emission at the tailpipe when run in all-electric mode (Markel and Simpson, 2007). Also, a study done by Elgowainy et al. (2009) conclude that in PHEV, the use of grid electricity displaces about 40–60 percent of petroleum, leading to a considerable decrease in oil consumption as compared to CVs. Hence, recognizing the benefit to the consumers and environment, and the potential to address the country's energy crisis, it is important to promote less polluting and energy-efficient PHEVs to replace the existing CVs without disrupting the general travel pattern of Indian commuters for a sustainable future.

1.1. Need for the study

Although the Indian Government has taken several policy initiatives to promote EVs, the industry is still in its early stages of adoption. As per the report of Global EV outlook, 2019, only 3300 electric four-wheelers were sold in India in 2018 (IEA, Global EV Outlook, 2019). The number of electric four-wheelers accounts for less than 1 % share in the Indian four-wheeler market. The insignificant share implies that consumers have a low sense of assurance towards the vehicle and infrastructure-related characteristics of EVs (Egbue and Long, 2012). Moreover, being unaware or having partial knowledge about the new alternative might also result in the reluctance to embrace the new vehicle technology, leading to subsequent rejection (Goel et al., 2021). Therefore, the success of all government initiatives to promote EVs is largely dependent on consumer preference for this new vehicle technology (Liao et al., 2017). Numerous research has been undertaken to investigate consumer preferences towards EVs in developed countries such as Canada (Higgins et al., 2017), United States (Helveston et al., 2015), Germany (Rommel and Sagebiel, 2021), Japan (Tanaka et al., 2014), The Netherlands (Hoen and Koetse, 2014), Italy (Danielis et al., 2020; Giansoldati et al., 2020), Australia (Gong et al., 2020), South Korea (Shin et al., 2015; Jung et al., 2021) and countries where EVs have already been accepted as mainstream transportation such as China (Qian et al., 2019; Li et al., 2020). However, there is a paucity of studies examining consumer preferences towards EVs in general and PHEVs in particular for developing countries such as India. It is important to investigate consumer perception towards PHEV-related attributes and identify the priority attributes that need necessary improvement by car manufacturers and the Government to increase the attractiveness of PHEVs among Indian consumers. While investigating consumer perception, it is also important to examine whether there is any difference in perception of attributes across cities. Similarly, it is important to explore whether there is any difference in perception of attributes within a city across different sociodemographic (such as gender, age, education, occupation, income, car ownership, etc.) and trip-related groups (such as trip frequency, purpose, distance, etc.).

With this background, the study aims to demonstrate a methodological approach for identifying a key set of priority attributes from a comprehensive list of attributes affecting the adoption of PHEVs. The identified set of independent attributes can subsequently be used for designing Stated Preference (SP) experiments to measure how consumers value them in terms of willingness to pay. For travel behavior analysis, a long list of attributes may place a high cognitive load upon respondents, which could further affect the data quality (Hensher et al., 2015). Hence, the identification of a small set of key attributes affecting the adoption of PHEV is necessary.

In the present research, the car-owning population is considered consumer of PHEVs. Also, the work is demonstrated with reference to consumers in two Indian megacities namely Delhi and Kolkata.

2. Literature review

A detailed review of past research literature indicates that the attributes affecting the adoption of EVs may be broadly divided into four categories, namely a) vehicle attributes, b) infrastructure attributes, c) policy attributes, and d) individual-related attributes. The consumer preference towards EVs is strongly influenced by several vehicle attributes such as purchase cost (Helveston et al., 2015; Gong et al., 2020), driving range (Tanaka et al., 2014; Rommel and Sagebiel, 2021), fuel cost (Helveston et al., 2015; Danielis et al., 2020), maintenance cost (Higgins et al., 2017; Lane et al., 2018), tailpipe emission (Nie et al., 2018), battery warranty (Higgins et al., 2017; Li et al., 2020), battery recharging time (Nie et al., 2018; Noel et al., 2019), fuel type (Hoen and Koetse, 2014), vehicle body type (Higgins et al., 2017), engine power (Rommel and Sagebiel, 2021), acceleration time (Noel et al., 2019) and maximum speed (Nie et al., 2018). Further, consumers' choice to purchase EVs is substantially influenced by infrastructure attributes such as the availability of charging stations relative to gas stations (Tanaka et al., 2014), distance from home to the nearest charging station (Rasouli and Timmermans, 2016), additional detour time (Hoen and Koetse, 2014) and charging station availability at different locations: at home, at work or in shopping malls, etc. (Huang et al., 2021). With respect to policy attributes, the review of prior research literature indicates that EV purchase decisions are majorly influenced by financial policy attributes such as purchase subsidy or rebate on upfront cost (Qian et al., 2019), purchase tax rebate/exemption (Wee et al., 2018) and road tax rebate/exemption (Hoen and Koetse, 2014; Li et al., 2020), and non-financial policy attributes such as free parking (Danielis et al., 2020), access to high occupancy vehicle (HOV)/bus lane (Hoen and Koetse, 2014; Gong et al., 2020) and free public charging stations (Lieven, 2015) on consumers' buying decision of EVs. An overview of various attributes included in the past studies on consumer preference towards EVs is presented in Table 1. With respect to individual-related attributes, consumer preference towards EVs is strongly influenced by sociodemographic attributes such as gender (Nie et al., 2018), age (Rommel and Sagebiel, 2021), income (Helveston et al., 2015), car ownership (Huang et al., 2021), vehicle body type/class choice (Higgins et al., 2017), education (Gong et al., 2020), household size (Noel et al., 2019), home-based charging capability/garage availability (Qian et al., 2019), experience (Lane et al., 2018) and knowledge (Giansoldati et al., 2020), and trip-related attributes such as commuting distance/trip length (Danielis et al., 2020), trip frequency and trip purpose (Hoen and Koetse, 2014).

The majority of the past studies have included several manifest/observed factors to investigate consumer preference for EVs. However, the decisions related to mode choice, especially for a new mode such as EVs, cannot be explained fully by the manifest/observed variables, they are also impacted by a number of latent/hidden attributes, representing consumers' attitude and perception towards a particular mode (Majumdar et al., 2015; Lane et al., 2018). Also, the prior studies are mainly based on stated preference applications to examine consumers' valuation for EV-related attributes. These studies, however, fail to explain how a small set of key attributes could be selected for designing the stated preference experiment. Therefore, the primary motive of this study is to demonstrate a methodological approach to obtain the key attributes influencing PHEV adoption, which could be further used for designing stated preference experiment.

Although it is crucial to identify priority attributes for valuation, it is equally important to investigate heterogeneity in consumer perception both within as well as between cities for any given attribute. For EVs in general and PHEVs in particular, efforts to investigate heterogeneity in consumers' perception of related attributes seem to be limited. For user responses collected on ordinal scale, heterogeneity is checked using non-parametric tests, such as Mann-Whitney *U* test (Nachar, 2008; MacFarland and Yates, 2016a) and Kruskal-Wallis H-test (Sheskin, 2003; MacFarland and Yates, 2016b). Mann-Whitney *U* test is used to check for

Table 1
Attributes included in the past studies on consumer preference towards EVs.

Study	Attributes included in the study
Tanaka et al. (2014)	Alternative fuel availability, driving range, emission reduction, home plug-in construction fee, fuel cost, purchase price
Hoen and Koetse (2014)	Recharge/Refueling time, additional detour time, driving range, monthly costs, purchase price, fuel type, policy measures
Helveston et al. (2015)	Fast charging capability, operating cost, acceleration time, vehicle type, purchase price
Rasouli and Timmermans (2016)	Distance from home to the nearest charging station, speed, time to charge battery, cruising range, net operating cost, net capital price
Higgins et al. (2017)	Charging availability, charging time, battery warranty, gasoline range, e-range, acceleration, tailpipe emissions, annual fuel cost, annual maintenance cost, purchase price
Nie et al. (2018)	Maximum speed, charging time, pollution, driving range, fuel costs, price
Lane et al. (2018)	Maintenance cost, fuel savings, driving range, recharge time, appearance, acceleration/power, charging availability, price, EV policies
Noel et al. (2019)	Acceleration, recharging time, driving range, fuel type, price
Qian et al. (2019)	Coverage of public slow charging station, coverage of public fast charging station, charging speed in slow charging post, driving range, annual running cost, purchase price, government subsidy
Gong et al. (2020)	Vehicle property: Vehicle body type, recharge time, set up cost, cost per km, driving range, electric vehicle price; support scheme: access to bus lane, rebate on upfront cost, rebate on parking fees
Danielis et al. (2020)	Fuel economy, max. distance between fast charging stations, driving range, fast charging time, purchase price, free parking in urban areas
Li et al. (2020)	Availability of charging station, fuel cost, charging time, driving range, price, policy incentives
Giansoldati et al. (2020)	% of service stations with fast charging infrastructure, driving range, annual operating cost, purchasing price
Rommel and Sagebiel (2021)	Running costs, range, power, availability of charging stations, price
Huang et al. (2021)	Annual running cost, driving range, coverage of public slow charging station, coverage of public fast charging station, charging speed in slow charging post, purchase price, government subsidy

differences or similarities between two independent populations. If the medians of two populations have same distribution, then they are considered statistically similar. Kruskal-Wallis H-test is used to compare variation among two or more independent populations (Kruskal and Wallis, 1952; Sheskin, 2003) and shares its wide application in transportation-related studies (Majumdar et al., 2015; Kwan et al., 2018; Sadhukhan et al., 2018). For instance, this test was employed to examine the difference in bicyclists' perception among different population subgroups (Majumdar et al., 2015), to compare the trip characteristics between the private motor vehicle and public transport (Kwan et al., 2018), and to investigate the influence of users' socioeconomic and trip characteristics on the importance rating of attributes related to the transfer facility at metro stations (Sadhukhan et al., 2018). Hence, Kruskal-Wallis H-test is found to be an appropriate technique for investigating heterogeneity in consumer perception (both within and between cities) for PHEV attributes.

The effect of consumers' attitude and perception towards PHEV adoption can be investigated using latent variable modeling techniques (Hair et al., 2012). Several techniques to develop latent variable models such as Exploratory Factor Analysis/EFA (Lane et al., 2018; Wei et al., 2020), Confirmatory Factor Analysis/CFA (Lai et al., 2015; Huang and Ge, 2019), and Structural Equation Modeling/SEM (He et al., 2018; Huang and Ge, 2019) have been extensively used to identify the causal relationship between the manifest/observed variables influencing EV choice. Among such studies, Lane et al. (2018) analyzed a total of 17 vehicle attributes that could influence one's vehicle purchase intention and used exploratory factor analysis (EFA) to extract four latent factors namely "vehicle cost", "vehicle design," "vehicle utility" and "vehicle ruggedness" influencing EV choice. Wei et al. (2020) used EFA to explore the latent factors impacting BEV adoption. By conducting a web-based questionnaire survey, the study assessed a total of 30 influence attributes and derived a set of six latent factors namely "design," "national awareness," "battery," "government policy," "cost of purchase and use" and "herd mentality" that affects consumer choice of BEV. Huang and Ge (2019) used confirmatory factor analysis (CFA) and structural equation modeling (SEM) to analyze factors influencing EV purchase intention. The study identified five latent constructs namely "attitude," "perceived behavior control," "cognitive status," "product perception" and "monetary incentive policy measures" having a positive effect on consumers' EV purchase intention. Whereas, "subjective norm" and "non-monetary incentive policy measures" were observed to have no significant impact on purchase intention. Among these techniques, EFA is the most appropriate technique to identify the correlation among a given set of variables, as it does not require any prior hypothesis regarding their relationship (Hair et al., 2012). In EFA, correlated variables are expected to be grouped into one latent factor, and variables belonging to different latent factors are considered to be independent (Mitra et al., 2005).

The review of literature indicates that the studies investigating the relationship between the PHEV choice and consumers' attitude and perception towards PHEV-related attributes are limited. To examine the impact of both manifest/observed and latent factors on PHEV choice, the present study demonstrates a stepwise methodology to identify the key attributes affecting the adoption of PHEVs. The identified attributes could further be used for valuing the attributes. In this regard, three basic research questions addressed in this study are as follows:

1. Does consumers' perception of PHEV attributes vary across cities?
2. Does consumers' perception of PHEV attributes vary across socio-demographic and trip-related groups within a city?
3. What are the latent factors influencing consumers' perception towards PHEVs?

3. Research methodology

The research methodology consists of five distinct steps for identifying the key attributes affecting the adoption of PHEVs. The adopted methodological flowchart is shown in Fig. 1.

A stepwise discussion of each methodological component is presented as follows:

Step 1. Design of Survey Instrument

Design of survey instrument involves two sub-tasks. First, identification of a comprehensive set of attributes affecting the adoption of PHEVs. Second, designing the questionnaire survey for data collection.

Step 2. Data Collection and Organization of Data

The designed survey instrument is used to collect consumers' importance rating responses for the selected attributes. Further, the collected data is organized for data analysis.

Step 3. Heterogeneity Investigation among Consumer Perception

Kruskal-Wallis H-test is employed to explore the heterogeneity in consumers' importance rating (both within and between cities) for PHEV-related attributes. The theoretical basis for Kruskal-Wallis H-test is discussed below:

Kruskal-Wallis H-test

Kruskal-Wallis H-test is a non-parametric test that is used for comparing two or more independent groups of equal or different sample sizes (Sheskin, 2003; MacFarland and Yates, 2016b). It is often viewed as non-parametric equivalent of parametric one-way analysis of variance (ANOVA), as the ranks are used in the test rather than the actual data points to compare the independent samples. The test examines if the distribution of any variable's median is same across different

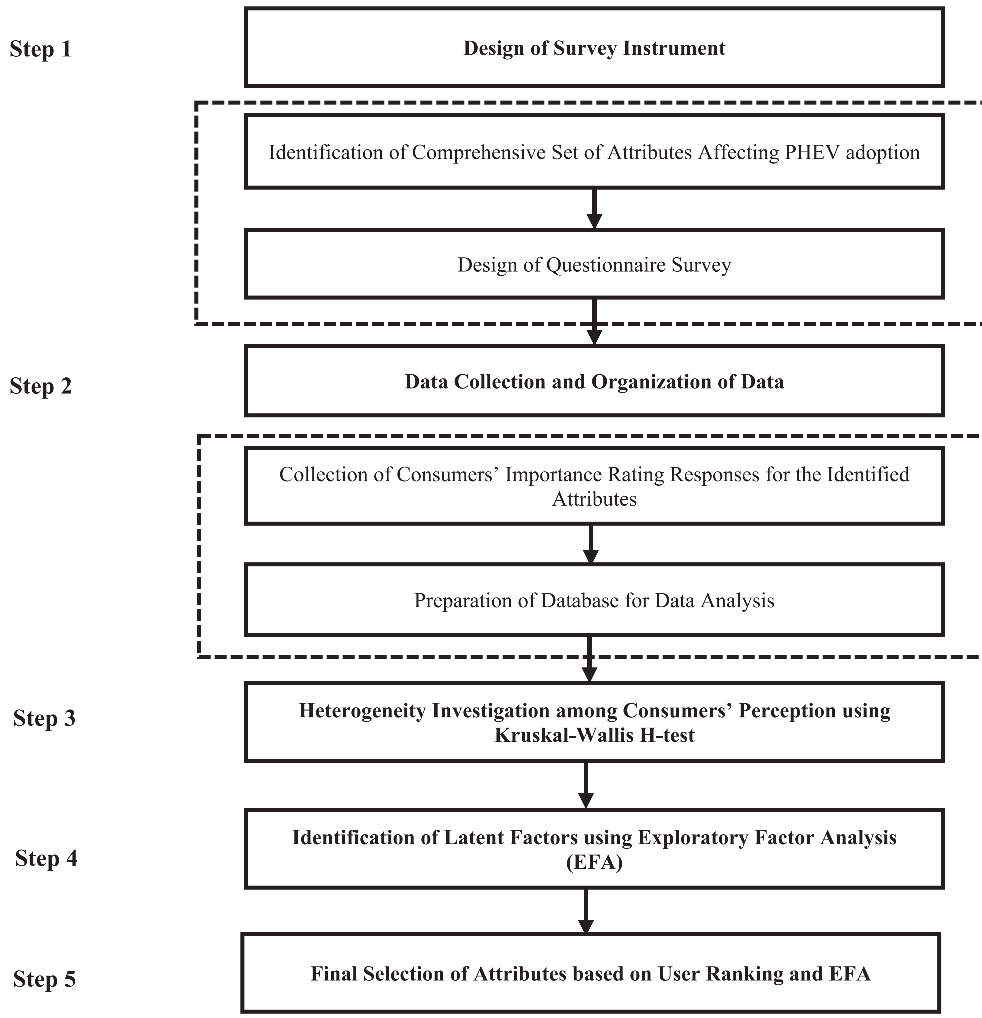

Fig. 1. Research methodology.

independent groups. The test statistic used in this test is called H statistic, and is defined as:

$$H = \frac{12}{n(n+1)} \sum \frac{T_i^2}{n_i} - 3(n+1) \quad (1)$$

Where,
n = Total sample size,
n_i = sample size of i^{th} sample,
T_i = sum of ranks for i^{th} sample.

Step 4. Identification of Latent Factors using EFA.

Exploratory Factor Analysis (EFA) is a multivariate statistical technique used to define the underlying structure among the variables (Washington et al., 2011). It helps to identify a reduced number of latent factors explaining maximum variance among a relatively larger set of variables (Hair et al., 2012). In EFA, the latent factors are identified by analyzing the inter-correlation among the variables, without imposing any prior hypothesis regarding their relationship (Williams et al., 2010). Hence, EFA is performed on the selected attributes to identify the latent factors influencing PHEV choice and explore the underlying relationship between the attributes. EFA involves five steps namely checking the data suitability, selecting the factor extraction method and criteria, selecting factor rotation method, checking goodness-of-fit of factor models, and interpretation and labeling of latent factors (Hair et al., 2012).

Step 5. Final Selection of Attributes based on User Ranking and EFA

Since identifying a small set of attributes to be used for valuation purposes is the main objective of the research, it is necessary to prioritize the variables loaded on each of the derived latent factors to select the important ones. For the stated purpose, Multi-criteria Decision Making (MCDM) method is used for ranking/prioritization of PHEV-related attributes based on consumers' importance rating data. MCDM methods such as RIDIT analysis (Bera and Maitra, 2019; Kar et al., 2022; Majumdar, 2017), Grey Relation Analysis (GRA) (Wu, 2002; Sadhukhan et al., 2015; Roy and Basu, 2019) and TOPSIS (Afsordegan et al., 2016; Rahim et al., 2018; Mahmood and Manzoor, 2021) have been widely used, both individually and in combination for ranking of attributes. The past studies indicate that the ranking of the attributes obtained from the analysis of ordinal rating data using RIDIT, TOPSIS, and GRA is found to be consistent, and any of the three methods could be used for the analysis of rating data in various application contexts (Majumdar, 2017; Sadhukhan et al., 2015; Roy and Basu, 2019; Mahmood and Manzoor, 2021). This study presents an application of GRA to evaluate consumers' importance rating data for deriving the rank order of PHEV-related attributes. A brief theoretical background on GRA is discussed below:

Grey Relation Analysis

The grey system theory was established by Deng in 1982 and has been proven useful for decision making with poor, incomplete, and uncertain information available for data analysis (Julong, 1989, Wu, 2002). The Grey Relational Analysis (GRA) is a method in grey system theory, which is distribution free and is used to analyze various relationships among the discrete data series based on Likert-type scale and make decisions in multiple attribute situations (Hsu et al., 2000). A stepwise methodology to perform GRA is presented in the following section:

Step 1: Generate reference data series 'x_0.'

$$x_0 = (x_{01}, x_{02}, \cdots\cdots x_{0n}) \tag{2}$$

Where 'n' is the number of respondents. In general, the 'x_0' reference data series consists of 'n' values representing the most favored responses

Step 2: Generate comparison data series 'x_i.'

$$x_i = (x_{i1}, x_{i2}, \cdots\cdots x_{in}) \quad \text{where, i} = 1, 2, \cdots, \text{m} \tag{3}$$

Where 'm' is the number of scale items. Therefore, there will be 'm' comparison data series, and each comparison data series contain 'n' values.

Step 3: Compute the difference data series Δ_i.

$$\Delta_i = (|x_{01} - x_{i1}|, |x_{02} - x_{i2}|, \cdots\cdots\cdots\cdots |x_{0n} - x_{in}|) \tag{4}$$

Step 4: Find the global maximum value Δ_{max} and minimum value Δ_{min} in the difference data series.

$$\Delta_{max} = \forall i^{max}(\max\Delta_i) \tag{5}$$

$$\Delta_{min} = \forall i^{min}(\min\Delta_i) \tag{6}$$

Step 5: Compute grey relation coefficient. Let $\gamma_i(k)$ represent the grey relational coefficient of the k^{th} data point in the i^{th} difference data series, then the coefficient can be calculated by Eq. (7).

$$\gamma_i(k) = \frac{\Delta_{min} + \xi\Delta_{max}}{\Delta_{i(k)} + \xi\Delta_{max}} \tag{7}$$

Where $\Delta_{i(k)}$ is the k^{th} value in the Δ_i difference data series and ξ is the distinguishing coefficient, $\xi \in [0,1]$. For calculation purposes, ξ is assumed as 0.5.

Step 6: Compute grey relation grade for each difference data series.

$$\Gamma_i = \frac{1}{n}\sum_{j=1}^{n}\gamma_i(j) \tag{8}$$

Where, Γ_i represent the grey relation grade for the i^{th} scale item and the data points in the series are assumed of the same weights.

Step 7: Sort Γ values into either descending or ascending order to facilitate the managerial interpretation of the results.

The following sub-sections include a discussion on Step 1 (design of survey instrument) and Step 2 (data collection and organization of data) of the methodology in the context of the present study.

3.1. Design of survey instrument

A survey instrument was designed, using which the relevant information was collected from consumers in Delhi and Kolkata for data analysis. The survey design included the identification of comprehensive set of attributes affecting the adoption of PHEVs and design of questionnaire.

3.1.1. Identification of comprehensive set of attributes affecting the adoption of PHEVs

Based on a thorough literature review (as discussed in section 2), consultation with policymakers and car manufacturers, and discussion with consumers (owners of conventional cars), a fairly exhaustive list of 22 attributes affecting the adoption of PHEVs was identified. Table 2 shows the attributes and their description.

3.1.2. Design of questionnaire

The designed questionnaire had three parts: i) introduction on PHEV as a mode, followed by attribute description using short text and pictorial illustration (for a few attributes) ii) questions on importance of attributes on a 7-point Likert-type scale, 1 (least important) to 7 (most important) and iii) questions on respondents' sociodemographic and trip-related characteristics. Before fielding the questionnaire, a pilot survey was conducted to estimate the time prerequisite to complete the questionnaire and to ensure that the questions were not difficult to understand. A sample of 50 responses was collected from each city, which is considered as adequate sample size for conducting a pilot survey (Sim and Lewis, 2012). According to the pilot survey, a respondent requires atleast 10 min to answer the questionnaire earnestly. Also, during the pilot survey, the majority of the respondents faced difficulty in understanding three attributes namely advance vehicle technology (AVT) option, battery recharging time, and public charging availability. Hence, the name and description of these attributes were modified to improve clarity, and the modified list of attributes considered for the main survey is shown in Table 2.

Table 2
Attributes and their description.

Attribute	Description of the attribute
Purchase Cost (PC)	Cost that consumer pays to own a car
Fuel Type (FT)	Type of fuel or energy source used to run the car such as gasoline, diesel, electricity, etc.
Advance Vehicle Technology (AVT) option	A group of smart car options that improve driver/vehicle safety, fuel efficiency, driving experience, etc.
Gasoline/Diesel Range (GDR)	Maximum distance a car can travel on a full tank
Fuel Cost (FC)	Yearly expenditure/cost to run the car
Maintenance Cost (MC)	Yearly expenditure/cost to maintain the car in good working condition
Battery Range (BR)	Maximum distance a car can travel on full battery
Gadgets (GG)	Electronic devices or tools such as cell phone charger, dashcam, blind spot mirrors, heads-up display, rear-view camera, defogger, etc.
Appearance (AP)	Interior and exterior looks, shape, and colour of a car
Tailpipe Emission (TE)	Pollutants discharged from the tailpipe of a car such as CO_2, NOx, SO_2, etc.
Air Conditioning (AC)	A system for controlling the humidity, ventilation, and temperature inside a car
Battery Warranty (BW)	A type of guarantee that a manufacturer makes promising to repair or exchange the battery within a specified time period if it does not function as originally described or intended
Resale Value (RV)	The amount of money received if the vehicle is sold in future after use
Safety (SF)	Ability of a car to reduce the risk of exposure to injuries during the event of an accident
Security (SR)	Ability of a car to protect itself from any form of theft, damage, or danger
Engine Power (EP)	Maximum power that an engine of a car can produce
Battery Recharging Time (BRT)	Time taken to fully recharge the battery
Acceleration Time (AT)	Time taken by a car to reach a speed from 0 to 100 km/h
Maximum Speed (MS)	Highest speed that can be attained by a car
Public Charging Availability (PCA)	Density of public charging stations as compared to fuel stations
Vehicle Body Type (VBT)	Different car classifications such as hatchback, sedan, sports utility vehicle, etc.
Seating Comfort (SC)	Level of comfort experienced while traveling in the car

3.2. Data collection and organization of data

The final version of the questionnaire was fielded during February to April 2018. The data was collected by a team of five enumerators (including the author). Initially, the questionnaire survey was thoroughly explained to the enumerators in the research lab. Thereafter, during pilot survey, the enumerators underwent extensive training so that they could collect the data effectively and independently during the main survey. The trained enumerators collected data from survey respondents in Delhi and Kolkata using computer assisted personal interviewing (Sainsbury et al., 1993). Shopping malls, residential complexes, offices, universities, colleges, and schools were several target locations selected to perform the interview. Firstly, the respondents were intercepted randomly and asked about their car ownership. The respondents who owned cars were interviewed further, i.e., the target population for the study was the car-owning population. Then, the car owners were asked three questions i) if they were aged 18 years or older and possessed a valid driving license, ii) if they intend to replace an existing car or buy a new car in the next five years and iii) if they were somewhat aware or educated about new vehicle technologies such as PHEVs and considered it as a potential alternative for conventional cars. The respondents who fulfilled all the criteria i.e., were 18 years of age or older and had a valid driving license, wish to replace an existing car or buy a new car in the next five years, and consider PHEV as a possible alternative to conventional cars were interviewed using the designed questionnaire. Among 1200 respondents intercepted in each city, only 505 (42.08 %) and 524 (43.67 %) of them in Delhi and Kolkata respectively met the aforementioned criteria and took part in the survey. During extensive cleaning and filtering, a percentage of respondents were eliminated if incomplete responses were received for a few questions and if the respondent completed the survey in less than 7 min. Furthermore, while collecting the data, vehicle body type owned by the respondents was also recorded. During data organization, it was observed that the majority of the cars owned by the respondents in both cities were hatchback or sedan cars. Hence, a few survey responses from the owners of other vehicle body types were excluded for the subsequent study. As per Society of Indian Automobile Manufacturers (SIAM) guidelines for vehicle classification, hatchback consists of “Mini” (vehicle up to 3,400 mm length) and “Compact” (vehicles between 3,401 and 4,000 mm in length) cars (SIAM, 2012). On the other hand, sedan includes “Midsize” (vehicles between 4,001 and 4,500 mm in length) and “Executive” (vehicles between 4,501 and 4,700 mm length) cars. The final dataset comprised 428 and 437 respondents for Delhi and Kolkata respectively. To represent an infinite population with 95 % confidence level, the sample responses for both cities met the minimum sample size requirement (384) (Taherdoost, 2017).

4. Results

This section presents the preliminary investigation and data description, results of step 3 of the methodology, which checks for heterogeneity among consumers’ perception, followed by step 4, which presents the outcomes of EFA on consumers’ perception, and lastly step 5, which discusses the selection of priority attributes based on EFA and GRA.

4.1. Preliminary investigation and data description

As stated earlier, the target population for the study included car owning population in Delhi and Kolkata. The Indian census manual (Ministry of Home Affairs (MHA), 2011) does not provide any sociodemographic data on car owning population. Thus, it was not possible to determine if the sample was representative of the target population. Hence, sociodemographic data of the urban population of Delhi and Kolkata as available in the Indian census manual was used for broad level comparison with respective sample data. Table 3 presents the comparison of descriptive statistics between sample and census data. It may be observed from Table 3 that the sample under-represents women and over-represents educated individuals. This might be due to two probable reasons. First, only the car owners are included in the sample data. Second, during data collection, female respondents made up a sizable portion of non-responsive samples since they were relatively less willing to participate in the questionnaire survey as compared to males. As a result, the sample obtained from both cities indicates a notable skewness towards male respondents. However, age distribution of the sample for both cities is fairly close to the population statistics. The income distribution could not be compared due to the non-availability of the data in the Indian census manual.

Table 3
Comparing sample and census data.

Characteristics		Delhi		Kolkata	
		Sample	Population	Sample	Population
Sample size		428		437	
Gender	Male	85 %	54 %	84 %	52 %
	Female	15 %	46 %	16 %	48 %
Age (Years)	Less than 35	58 %	66 %	41 %	53 %
	35 or above	42 %	34 %	59 %	47 %
Education	Up to Higher Secondary	56 %	83 %	54 %	82 %
	Graduate or Higher	44 %	17 %	46 %	18 %
Monthly Household Income (INR*/month)	Less than 1,50,000	64 %	–	83 %	–
	1,50,000 or more	36 %	–	17 %	–
Car Ownership	1	64 %	–	78 %	–
	2 or more	36 %	–	22 %	–
Vehicle Body Type Owned	Hatchback	67 %	–	78 %	–
	Sedan	33 %	–	22 %	–
Garage Availability	Yes	49 %	–	85 %	–
	No	51 %	–	15 %	–
Average Commuting Distance	Less than 30 km	31 %	–	68 %	–
	30 km or more	69 %	–	32 %	–

*1 INR = USD 0.014 (approximately)

4.2. Heterogeneity investigation (both within and between cities) among consumer perception

Using Kruskal-Wallis H-test, heterogeneity in consumers’ perception was explored (i) between cities, i.e., across Delhi and Kolkata, and (ii) within each city across different sociodemographic and trip-related groups. To test for heterogeneity, Kruskal-Wallis H-test was conducted using SPSS statistical (version 22.0) software (SPSS, 2013). The chi-square and associated asymptotic significance or p values obtained against each attribute for different population sub-groups are shown in Table 4. For evidence of significant heterogeneity in the perception of attributes across a specific population sub-group, the asymptotic significance or p-value should be $\leq$ 0.05, for 95 % confidence interval. Hence, in Table 4, the attributes with p values $\leq$ 0.05 indicate the cases with statistically significant heterogeneity. Some of the key observations and findings from the heterogeneity study are discussed below.

4.2.1. Heterogeneity investigation of consumers’ perception between two cities

Consumers’ perception of various attributes was compared across different user groups between Delhi and Kolkata. The results indicate a significant difference in perception for several attributes (e.g. purchase cost, AVT option, battery range, gadgets, appearance, tailpipe emission,

Table 4
Results of heterogeneity investigation (within and between cities): Kruskal-Wallis H-test.

Characteristics		Test Statistics	PC	FT	AVT	GDR	FC	MC	BR	GG	AP	TE	AC
Between City Heterogeneity													
Between Delhi and Kolkata		Chi-square	4.188	0.025	5.919	0.307	0.047	0.138	4.236	15.690	14.743	14.741	7.196
		p-value	0.041	0.874	0.015	0.580	0.829	0.710	0.040	0.000	0.000	0.000	0.007
Within City Heterogeneity													
Gender	Delhi	Chi-square	0.216	0.754	0.380	0.050	2.634	4.295	0.111	7.451	4.181	0.661	0.034
		p-value	0.642	0.385	0.538	0.824	0.105	0.038	0.739	0.006	0.042	0.416	0.853
	Kolkata	Chi-square	0.200	2.335	0.118	1.292	4.112	15.271	0.142	0.057	4.182	0.013	0.718
		p-value	0.655	0.126	0.731	0.256	0.043	0.000	0.706	0.812	0.041	0.911	0.397
Age	Delhi	Chi-square	0.554	0.255	0.298	4.631	4.959	0.016	5.297	1.656	5.857	8.095	0.933
		p-value	0.456	0.614	0.585	0.031	0.026	0.901	0.021	0.198	0.016	0.004	0.334
	Kolkata	Chi-square	0.542	0.005	5.589	0.666	2.109	0.010	0.001	2.069	0.028	0.980	0.580
		p-value	0.462	0.946	0.018	0.414	0.146	0.921	0.986	0.150	0.866	0.322	0.446
Education	Delhi	Chi-square	0.707	7.941	2.678	3.111	3.481	20.669	2.561	0.028	3.079	6.663	0.455
		p-value	0.400	0.005	0.102	0.078	0.062	0.000	0.110	0.868	0.079	0.010	0.500
	Kolkata	Chi-square	2.865	0.088	1.550	0.617	0.246	0.012	0.365	0.002	0.718	0.091	1.435
		p-value	0.091	0.766	0.213	0.432	0.620	0.912	0.546	0.996	0.397	0.763	0.231
Monthly Household Income	Delhi	Chi-square	4.009	0.118	0.281	0.486	3.680	0.151	0.001	0.025	0.166	0.836	0.003
		p-value	0.045	0.732	0.596	0.486	0.055	0.697	0.998	0.874	0.683	0.361	0.957
	Kolkata	Chi-square	35.311	0.648	0.771	1.159	8.817	1.224	0.297	0.002	1.270	0.078	5.873
		p-value	0.000	0.421	0.380	0.282	0.003	0.269	0.586	0.993	0.260	0.780	0.015
Car Ownership	Delhi	Chi-square	4.108	0.365	0.634	1.750	2.778	0.317	0.071	2.120	6.387	2.892	4.576
		p-value	0.043	0.546	0.426	0.186	0.096	0.573	0.790	0.145	0.011	0.089	0.032
	Kolkata	Chi-square	18.894	0.874	1.971	4.798	4.390	2.584	2.286	7.501	0.498	0.692	0.529
		p-value	0.000	0.350	0.160	0.029	0.036	0.108	0.131	0.006	0.480	0.406	0.467
Vehicle Body Type Owned	Delhi	Chi-square	1.317	1.622	1.248	1.383	0.082	0.010	3.814	7.156	1.734	2.341	0.875
		p-value	0.251	0.203	0.264	0.240	0.775	0.922	0.051	0.007	0.188	0.126	0.349
	Kolkata	Chi-square	0.578	0.053	0.001	0.163	0.148	3.657	2.306	0.075	3.059	1.102	1.825
		p-value	0.447	0.818	0.986	0.686	0.701	0.056	0.129	0.784	0.080	0.294	0.177
Garage Availability	Delhi	Chi-square	1.395	1.858	8.146	2.794	0.693	2.943	0.858	0.059	0.003	0.804	0.083
		p-value	0.238	0.173	0.004	0.095	0.405	0.086	0.354	0.808	0.988	0.370	0.773
	Kolkata	Chi-square	1.585	4.009	0.007	0.235	0.001	2.672	0.573	2.287	1.938	0.256	1.636
		p-value	0.208	0.045	0.932	0.628	0.979	0.102	0.449	0.130	0.164	0.613	0.201
Avg. Commuting Distance	Delhi	Chi-square	3.186	3.470	4.798	1.157	6.921	2.306	0.174	1.869	0.733	7.941	0.428
		p-value	0.073	0.068	0.029	0.283	0.009	0.129	0.672	0.172	0.390	0.005	0.509
	Kolkata	Chi-square	6.375	0.135	0.138	2.069	0.165	0.210	0.111	1.190	0.796	0.161	0.314
		p-value	0.013	0.713	0.711	0.151	0.667	0.646	0.739	0.276	0.378	0.688	0.575

Note: PC: Purchase Cost, FT: Fuel Type, AVT: Advance Vehicle Technology option, Gasoline/Diesel Range, FC: Fuel Cost, MC: Maintenance Cost, BR: Battery Range, GG: Gadgets, AP: Appearance, TE: Tailpipe Emission, AC: Air Conditioning

Characteristics		Test Statistics	BW	RV	SF	SR	EP	BRT	AT	MS	PCA	VBT	SC
Between City Heterogeneity													
Between Delhi and Kolkata		Chi-square	0.716	0.002	0.599	0.359	5.855	42.269	9.918	17.877	0.038	0.005	4.009
		p-value	0.398	0.990	0.439	0.549	0.016	0.000	0.002	0.000	0.846	0.944	0.045
Within City Heterogeneity													
Gender	Delhi	Chi-square	3.814	0.404	0.094	0.953	6.082	2.568	4.857	4.009	1.589	3.975	0.493
		p-value	0.051	0.525	0.759	0.329	0.014	0.109	0.028	0.045	0.207	0.046	0.483
	Kolkata	Chi-square	0.106	0.446	1.125	1.504	0.766	2.090	0.078	2.019	0.161	5.679	0.537
		p-value	0.745	0.504	0.289	0.220	0.381	0.148	0.780	0.155	0.689	0.017	0.464
Age	Delhi	Chi-square	9.008	1.751	4.236	2.382	3.688	3.660	1.047	12.138	19.263	19.124	0.007
		p-value	0.003	0.186	0.040	0.123	0.055	0.056	0.306	0.000	0.000	0.000	0.932
	Kolkata	Chi-square	2.020	2.121	1.321	2.727	3.076	2.534	0.180	10.927	0.347	0.156	2.123
		p-value	0.155	0.145	0.250	0.099	0.079	0.111	0.671	0.001	0.556	0.692	0.145
Education	Delhi	Chi-square	0.098	7.688	0.048	0.112	5.647	11.820	2.550	0.516	2.934	2.710	0.006
		p-value	0.755	0.006	0.827	0.738	0.017	0.001	0.110	0.472	0.087	0.100	0.939
	Kolkata	Chi-square	3.975	1.063	0.026	2.731	3.682	0.158	2.662	0.009	2.558	0.014	0.028
		p-value	0.046	0.302	0.871	0.098	0.055	0.691	0.103	0.923	0.110	0.905	0.868
Monthly Household Income	Delhi	Chi-square	1.395	6.638	0.011	2.273	4.700	1.946	2.531	5.559	0.002	1.607	1.022
		p-value	0.237	0.010	0.917	0.132	0.030	0.163	0.112	0.018	0.997	0.205	0.312
	Kolkata	Chi-square	1.654	0.025	1.064	2.684	1.788	0.264	0.569	0.635	1.858	1.743	0.261
		p-value	0.198	0.876	0.302	0.101	0.181	0.607	0.451	0.426	0.173	0.187	0.609
Car Ownership	Delhi	Chi-square	0.921	1.082	0.119	0.340	0.648	1.195	1.631	2.517	0.557	0.155	0.028
		p-value	0.337	0.298	0.730	0.560	0.421	0.274	0.202	0.113	0.455	0.694	0.868
	Kolkata	Chi-square	0.146	0.006	0.021	0.825	8.596	0.117	2.161	4.112	0.180	2.330	7.292
		p-value	0.702	0.939	0.886	0.364	0.003	0.733	0.142	0.043	0.671	0.127	0.007
Vehicle Body Type Owned	Delhi	Chi-square	2.008	0.004	0.506	0.138	0.056	1.719	0.411	0.060	1.427	2.694	0.129
		p-value	0.156	0.948	0.477	0.711	0.814	0.190	0.521	0.806	0.232	0.101	0.720
	Kolkata	Chi-square	0.501	0.999	0.381	0.349	1.839	0.106	0.893	0.017	0.080	2.834	9.318
		p-value	0.479	0.318	0.537	0.555	0.175	0.745	0.345	0.897	0.777	0.092	0.002
Garage Availability	Delhi	Chi-square	5.107	0.910	0.547	2.789	2.934	4.706	3.826	3.137	2.953	2.400	0.398
		p-value	0.024	0.340	0.459	0.095	0.087	0.030	0.050	0.077	0.086	0.121	0.528
	Kolkata	Chi-square	0.730	0.058	1.775	3.185	0.264	0.212	0.003	0.303	0.374	0.295	7.537

(*continued on next page*)

Table 4 (*continued*)

Characteristics		Test Statistics	BW	RV	SF	SR	EP	BRT	AT	MS	PCA	VBT	SC
		p-value	0.393	0.810	0.183	0.074	0.608	0.645	0.956	0.582	0.541	0.587	0.006
Avg. Commuting Distance	Delhi	Chi-square	2.161	3.481	0.017	0.009	1.223	0.162	0.293	4.181	0.002	2.109	0.150
		p-value	0.142	0.062	0.895	0.924	0.267	0.687	0.589	0.042	0.968	0.146	0.699
	Kolkata	Chi-square	0.694	0.412	0.293	1.503	0.800	0.002	0.109	1.504	0.137	0.103	2.934
		p-value	0.404	0.519	0.589	0.222	0.374	0.996	0.741	0.220	0.286	0.748	0.087

Note: BW: Battery Warranty, RS: Resale Value, SF: Safety, SR: Security, EP: Engine Power, BRT: Battery Recharging Time, AT: Acceleration Time, MS: Maximum Speed, PCA: Public Charging Availability, VBT: Vehicle Body Type, SC: Seating Comfort

air conditioning, engine power, battery recharging time, acceleration time, maximum speed, and seating comfort) across the two cities. The results reveal that the actual requirements of PHEVs are likely to vary across cities as per city context. Hence, it is essential to incorporate city characteristics and their respective consumers' perspective while developing the marketing strategy for increased PHEV penetration.

4.2.2. Heterogeneity investigation based on sociodemographic characteristics

In order to investigate the impact of sociodemographic characteristics on consumers' perception, a detailed investigation was carried out with respect to gender, age, education, monthly household income, car ownership, vehicle body type owned, and garage availability for Delhi and Kolkata separately. For example, in Delhi, consumers are observed to perceive attributes such as gasoline/diesel range, fuel cost, battery range, appearance, tailpipe emission, battery warranty, safety, maximum speed, public charging availability, and vehicle body type significantly differently with respect to age. In Kolkata, with respect to age, a significant difference in consumer perception is observed for AVT option and maximum speed. Monthly family income is observed to significantly influence consumer perception towards PHEVs. In Delhi, attributes such as purchase cost, resale value, engine power, and maximum speed are perceived statistically differently by consumers belonging to different income groups. In Kolkata, a significant difference in consumer perception is observed for attributes such as purchase cost, fuel cost, and air conditioning. Similarly, with respect to other sociodemographic variables, differences in perception for several attributes were observed for both cities. The difference in consumer perception clearly indicates that sociodemographic characteristics strongly influence consumers' perception towards PHEV attributes. Understanding these demographic differences in perception would help policymakers develop more effective, inclusive, and targeted strategies to promote the adoption of PHEVs while addressing specific concerns or barriers faced by different demographic groups.

4.2.3. Heterogeneity investigation based on trip-related characteristics

Within city heterogeneity was also investigated with respect to trip-related characteristics-average commuting distance. In Delhi, attributes such as AVT option, fuel cost, tailpipe emission, and maximum speed are perceived statistically differently by consumers with short and long average commuting distances. In Kolkata, consumers are observed to perceive different attributes similarly except for purchase cost with respect to commuting distance. The results reveal that trip characteristics such as average commuting distance have substantial influence on consumer preference for PHEV. Aligning policies with varying consumer preferences could foster wider PHEV adoption across diverse commuting segments.

Overall, the clear evidence of both between cities and within city heterogeneity among consumers' perception towards PHEV attributes indicates the need to perform separate analyses for Delhi and Kolkata. Subsequently, for identifying the latent factors influencing the choice of PHEVs, Exploratory Factor Analysis (EFA) models were developed for Delhi and Kolkata separately.

4.2.4. Validation test for heterogeneity results

To check for the consistency of the results, parametric one-way ANOVA was performed on the dataset of Delhi and Kolkata to investigate heterogeneity in consumers' perception within and between cities using SPSS software (SPSS, 2013). The results including F statistics and p values for each attribute across different population sub-samples are reported in Table 5. In Table 5, the attributes with p values ≤ 0.05, for 95 % confidence interval indicate the cases with statistically significant heterogeneity. It may be observed from Table 5 that despite the distinct assumptions underlying parametric one-way ANOVA and non-parametric Kruskal-Wallis H-test, the findings regarding the differences among population sub-groups remain consistent.

4.3. Identification of latent factors using EFA

As discussed in the methodology section, EFA is a multivariate statistical technique used to identify the underlying structural relationship among a given set of variables. M−plus statistical package developed by Mplus User's Guide 5, (2015), which is capable of developing latent variable models with categorical indicator variables was used to perform EFA on consumers' perception of attributes. A stepwise EFA procedure for the identification of latent factors is discussed below.

Data Suitability

Data suitability was checked based on sample size and sample adequacy test. In this study, sample size of 428 for Delhi and 437 for Kolkata satisfies the minimum sample size of 300 (Hair et al., 2012; Comrey and Lee, 2013) considered as adequate to perform EFA. The sample (N) to variable ratio (p) of 19.45: 1 for Delhi and 19.86: 1 for Kolkata also lies within the acceptable range of 3:1 to 20:1 (Hair et al., 2012) for factor analysis.

Kaiser-Meyer-Olkin (KMO) and Bartlett's Sphericity tests were used to assess the appropriateness of performing factor analysis on the sample dataset. KMO is a measure of sampling adequacy that indicates the proportion of variances in the variables that might be caused by underlying factors (Williams et al., 2010; Gaskin and Happell, 2014). For the dataset of Delhi and Kolkata, KMO values were found to be closer to 1.00 (Delhi = 0.830 and Kolkata = 0.806), which is considered satisfactory for commencing factor analysis. Bartlett's test of Sphericity is used to test the null hypothesis that the correlation matrix is an identity matrix, which indicates that variables are unrelated (Williams et al., 2010; Hair et al., 2012). A statistically significant Bartlett's Sphericity Test, with a significance level of 0 for both cities (i.e., $p < 0.05$) indicates that there is sufficient interrelationship among the variables, and the datasets are fit to perform factor analysis.

Factor Extraction

The robust weighted least squares (WLS) approach with weighted least squares means and variance (WLSMV) as the estimator in M plus was used to perform EFA with categorical indicator variables. The Kaiser criteria (eigenvalue > 1) is fulfilled for all the latent factors derived by analyzing the data collected from the two cities.

Factor Rotation

Factor rotation redistributes the variance of the initial set of factors to a simpler, and theoretically more meaningful factor pattern (Hair et al., 2012). There are several factor rotation methods reported in the literature for EFA, namely QUARTIMAX, VARIMAX, EQUIMAX,

Table 5
Results of heterogeneity investigation (within and between cities): one-way ANOVA test.

Characteristics		Test Statistics	PC	FT	AVT	GDR	FC	MC	BR	GG	AP	TE	AC
Between City Heterogeneity													
Between Delhi and Kolkata		F-value	6.485	0.014	10.092	0.872	2.857	0.868	5.548	14.871	11.409	13.402	8.300
		p-value	0.011	0.905	0.002	0.351	0.092	0.352	0.019	0.000	0.001	0.000	0.004
Within City Heterogeneity													
Gender	Delhi	F-value	0.303	0.689	0.542	0.140	2.980	5.550	0.403	5.810	3.826	1.523	0.416
		p-value	0.583	0.407	0.462	0.708	0.076	0.019	0.526	0.017	0.048	0.218	0.520
	Kolkata	F-value	0.363	2.171	0.055	1.224	4.270	14.374	0.017	0.072	5.634	0.114	0.816
		p-value	0.547	0.142	0.814	0.269	0.040	0.000	0.896	0.789	0.018	0.736	0.367
Age	Delhi	F-value	0.939	0.697	0.000	6.106	8.853	0.460	6.745	3.428	4.826	7.754	0.822
		p-value	0.334	0.405	0.983	0.014	0.003	0.498	0.010	0.064	0.029	0.006	0.366
	Kolkata	F-value	0.033	0.072	7.935	1.653	0.539	0.083	0.001	1.441	0.000	0.709	0.916
		p-value	0.856	0.788	0.005	0.200	0.464	0.773	0.978	0.231	0.993	0.400	0.339
Education	Delhi	F-value	0.823	14.959	1.895	2.673	3.589	24.649	0.974	0.011	1.964	12.747	0.486
		p-value	0.365	0.000	0.170	0.091	0.057	0.000	0.325	0.915	0.162	0.000	0.487
	Kolkata	F-value	2.485	1.002	0.976	0.640	0.000	0.250	0.019	0.198	0.374	0.152	1.451
		p-value	0.116	0.318	0.324	0.424	0.990	0.617	0.891	0.656	0.541	0.697	0.229
Monthly Household Income	Delhi	F-value	4.063	0.288	0.450	0.403	3.661	0.390	0.087	0.022	0.073	0.205	0.179
		p-value	0.045	0.592	0.503	0.526	0.056	0.533	0.769	0.882	0.787	0.651	0.673
	Kolkata	F-value	51.691	1.146	1.921	0.464	6.955	0.965	0.818	0.016	1.580	0.049	6.592
		p-value	0.000	0.285	0.167	0.496	0.009	0.327	0.367	0.900	0.210	0.825	0.011
Car Ownership	Delhi	F-value	3.973	0.583	0.740	1.411	1.959	0.180	0.211	2.479	5.814	1.763	4.801
		p-value	0.041	0.446	0.391	0.236	0.163	0.672	0.647	0.117	0.017	0.186	0.029
	Kolkata	F-value	23.555	1.079	1.362	3.860	4.218	2.775	1.658	7.830	0.436	0.509	0.912
		p-value	0.000	0.300	0.244	0.050	0.041	0.097	0.199	0.005	0.509	0.476	0.340
Vehicle Body Type Owned	Delhi	F-value	1.582	1.420	0.673	2.481	0.006	0.342	1.735	7.276	1.457	1.720	1.234
		p-value	0.210	0.235	0.413	0.117	0.939	0.559	0.189	0.008	0.229	0.191	0.268
	Kolkata	F-value	1.240	0.057	0.012	0.048	0.221	3.407	3.596	0.023	3.255	2.213	1.937
		p-value	0.266	0.811	0.914	0.827	0.638	0.066	0.059	0.879	0.072	0.138	0.165
Garage Availability	Delhi	F-value	1.491	1.652	6.002	1.301	1.831	2.054	0.317	0.024	0.455	0.994	0.562
		p-value	0.223	0.200	0.015	0.255	0.177	0.153	0.574	0.877	0.501	0.320	0.454
	Kolkata	F-value	2.160	4.508	0.093	0.011	0.066	2.401	0.044	2.712	1.472	0.111	2.210
		p-value	0.143	0.035	0.761	0.916	0.797	0.122	0.833	0.101	0.226	0.739	0.138
Avg. Commuting Distance	Delhi	F-value	2.588	0.571	3.853	0.331	5.649	1.172	0.456	2.671	0.489	6.586	0.139
		p-value	0.109	0.451	0.049	0.565	0.011	0.280	0.500	0.104	0.485	0.023	0.710
	Kolkata	F-value	6.937	0.246	0.297	1.738	0.362	0.177	0.455	0.518	1.513	0.463	0.750
		p-value	0.006	0.620	0.582	0.194	0.546	0.650	0.492	0.472	0.220	0.497	0.387

Note: PC: Purchase Cost, FT: Fuel Type, AVT: Advance Vehicle Technology option, Gasoline/Diesel Range, FC: Fuel Cost, MC: Maintenance Cost, BR: Battery Range, GG: Gadgets, AP: Appearance, TE: Tailpipe Emission, AC: Air Conditioning

Characteristics		Test Statistics	BW	RV	SF	SR	EP	BRT	AT	MS	PCA	VBT	SC
Between City Heterogeneity													
Between Delhi and Kolkata		F-value	1,962	0.261	0.015	0.030	4,328	9,713	5,406	20,647	0.015	0.789	4.182
		p-value	0.162	0.610	0.903	0.863	0.038	0.002	0.020	0.000	0.903	0.375	0.043
Within City Heterogeneity													
Gender	Delhi	F-value	3.814	0.504	0.358	0.980	6.388	3.714	5.348	5.122	1.493	4.067	1.137
		p-value	0.051	0.478	0.550	0.323	0.012	0.055	0.022	0.037	0.223	0.045	0.287
	Kolkata	F-value	0.188	0.746	0.547	0.388	0.204	1.984	0.008	1.397	0.073	6.048	0.706
		p-value	0.665	0.388	0.460	0.534	0.652	0.160	0.927	0.238	0.788	0.015	0.401
Age	Delhi	F-value	6.794	3.228	3.962	1.890	2.561	3.693	1.584	14.311	13.941	25.573	0.510
		p-value	0.010	0.074	0.045	0.171	0.111	0.056	0.209	0.000	0.000	0.000	0.476
	Kolkata	F-value	2.136	0.951	2.072	1.890	3.129	1.697	0.291	14.253	1.058	0.561	0.714
		p-value	0.145	0.330	0.151	0.170	0.078	0.194	0.590	0.000	0.305	0.454	0.399
Education	Delhi	F-value	0.028	8.533	0.000	0.009	4.593	11.167	3.289	0.297	2.756	3.674	0.016
		p-value	0.866	0.004	0.998	0.926	0.033	0.001	0.081	0.586	0.098	0.061	0.899
	Kolkata	F-value	4.338	0.599	0.002	1.151	2.054	0.463	2.024	0.170	2.645	0.060	0.266
		p-value	0.038	0.439	0.965	0.284	0.153	0.497	0.156	0.680	0.105	0.807	0.606
Monthly Household Income	Delhi	F-value	3.331	9.562	0.113	0.954	5.400	2.591	3.794	6.070	0.008	2.008	0.373
		p-value	0.069	0.002	0.737	0.330	0.021	0.109	0.053	0.014	0.927	0.158	0.542
	Kolkata	F-value	2.049	0.046	0.754	1.205	1.557	0.261	0.211	0.560	2.529	1.575	0.043
		p-value	0.153	0.831	0.386	0.273	0.213	0.610	0.647	0.455	0.113	0.210	0.835
Car Ownership	Delhi	F-value	1.756	1.529	0.663	0.665	0.496	2.512	2.832	2.864	0.895	1.042	0.141
		p-value	0.186	0.218	0.416	0.416	0.482	0.114	0.094	0.092	0.345	0.308	0.708
	Kolkata	F-value	0.017	0.000	0.326	0.769	7.773	0.102	2.112	4.261	0.032	2.095	6.855
		p-value	0.898	0.990	0.568	0.381	0.006	0.749	0.147	0.042	0.857	0.149	0.009
Vehicle Body Type Owned	Delhi	F-value	2.156	0.002	1.566	0.055	0.525	3.487	0.113	0.002	0.542	1.570	0.726
		p-value	0.143	0.962	0.212	0.815	0.470	0.063	0.737	0.962	0.462	0.211	0.395
	Kolkata	F-value	0.789	0.920	0.024	0.865	2.884	0.810	0.600	0.080	0.203	3.097	8.701
		p-value	0.375	0.338	0.876	0.353	0.091	0.369	0.439	0.777	0.652	0.080	0.003
Garage Availability	Delhi	F-value	3.937	0.678	0.033	1.492	1.933	3.939	5.303	2.759	2.576	2.904	0.768
		p-value	0.049	0.411	0.855	0.223	0.166	0.049	0.022	0.098	0.110	0.090	0.382

(*continued on next page*)

Table 5 (*continued*)

Characteristics		Test Statistics	BW	RV	SF	SR	EP	BRT	AT	MS	PCA	VBT	SC
	Kolkata	F-value	0.249	0.296	2.808	1.933	0.305	2.691	0.002	0.344	0.277	0.101	4.945
		p-value	0.618	0.587	0.095	0.165	0.581	0.102	0.965	0.558	0.599	0.751	0.027
Avg. Commuting Distance	Delhi	F-value	1.560	0.006	3.714	0.056	0.464	2.175	2.035	3.998	0.439	2.452	2.091
		p-value	0.213	0.938	0.055	0.812	0.496	0.142	0.155	0.043	0.508	0.119	0.149
	Kolkata	F-value	0.451	0.606	1.140	1.323	2.737	0.826	1.513	0.811	0.451	0.141	3.636
		p-value	0.502	0.437	0.286	0.251	0.099	0.364	0.220	0.369	0.502	0.708	0.058

Note: BW: Battery Warranty, RS: Resale Value, SF: Safety, SR: Security, EP: Engine Power, BRT: Battery Recharging Time, AT: Acceleration Time, MS: Maximum Speed, PCA: Public Charging Availability, VBT: Vehicle Body Type, SC: Seating Comfort

PROMAX, etc. (Williams et al., 2010; Hair et al., 2012). In this study, VARIMAX, the simplest and most widely used orthogonal factor rotation technique was adopted (Abdi, 2003). VARIMAX rotation maximizes the sum of the variance of the squared loading within each column of the loading matrix. Each factor tends to have either large or small loadings of any particular variable, thus simplifying the factor interpretation (Kaiser, 1958; Abdi, 2003).

Goodness-of-fit Statistics

Tucker-Lewis Index (TLI), Comparative Fit Index (CFI), and Root Mean Square Error of Approximation (RMSEA) were calculated to evaluate the overall goodness-of-fit of the estimated models (Hair et al., 2012). For the estimated models of Delhi and Kolkata, TLI and CFI are close to 1, and RMSEA is less than 0.05, which is indicative of a good model fit.

4.3.1. Interpretation and labeling of latent factors

Initially, the rotated factor loadings for each variable were explored for their highest significant loading on a particular latent factor. Variables with high correlation were loaded onto a common factor. Finally, the latent factors were labeled based on their appropriateness to represent the loaded variable (shown in Table 6). Due to weaker loading and lack of significant association with any of the latent factors, fuel type was dropped for the Delhi city sample, and fuel type and resale value were dropped for the Kolkata city sample. As a rule of thumb, the variables should have a rotated factor loading of at least $|0.4|$ (i.e., $\geq +0.4$ or ≤ -0.4) onto the factors to be considered important (Rahn, 2014). Hence, the variables with a factor loading value of < 0.4 were dropped or considered unimportant. Also, for most of the variables, other than factors with highest significant loading, a very low loading (i.e., < 0.2) was observed with other constructs. Hence, the cross-loading was found to be insignificant. The latent factors extracted for Delhi and Kolkata are discussed below.

Delhi

Five latent factors were extracted from the Delhi data. “Monetary factors” includes purchase cost, gasoline/diesel range, fuel cost, maintenance cost, and resale value. “Pollution and safety aspects” incorporates AVT option, safety, security, seating comfort, and tailpipe emission. “Aesthetics” incorporates vehicle body type, gadgets, appearance, and air conditioning. “Charging components” includes public charging availability and battery recharging time. Lastly, “performance factors” incorporates engine power, acceleration time, battery range, maximum speed, and battery warranty.

Kolkata

Among the five latent factors extracted for Kolkata city sample, “monetary factors” includes purchase cost, gasoline/diesel range, fuel cost, and maintenance cost. “Safety-related factors” includes AVT option, safety, security, seating comfort, and gadgets. “Aesthetics” includes vehicle body type, appearance, and air conditioning. “PHEV-specific factors” incorporates battery range, public charging availability, and battery warranty. Lastly, “performance factors” incorporates maximum

Table 6
Latent factor labeling for Delhi and Kolkata.

Latent factor	Delhi		Latent factor	Kolkata	
	Variable	Factor loading		Variable	Factor Loading
Monetary Factors	Purchase Cost (PC)	0.483	Monetary Factors	Purchase Cost (PC)	0.511
	Gasoline/Diesel Range (GDR)	0.553		Gasoline/Diesel Range (GDR)	0.408
	Fuel Cost (FC)	0.769		Fuel Cost (FC)	0.828
	Maintenance Cost (MC)	0.683		Maintenance Cost (MC)	0.601
	Resale Value (RV)	0.520			
Pollution and Safety Aspects	Advance Vehicle Technology (AVT) option	0.487	Safety-related Factors	Advance Vehicle Technology (AVT) option	0.566
	Safety (SF)	0.935		Safety (SF)	0.885
	Security (SR)	0.853		Security (SR)	0.795
	Seating Comfort (SC)	0.662		Seating Comfort (SC)	0.482
	Tailpipe Emission (TE)	0.531		Gadgets (GG)	0.428
Aesthetics	Vehicle Body Type (VBT)	0.483	Aesthetics	Vehicle Body Type (VBT)	0.533
	Gadgets (GG)	0.479		Appearance (AP)	0.629
	Appearance (AP)	0.718		Air Conditioning (AC)	0.419
	Air Conditioning (AC)	0.557			
Charging Components	Public Charging Availability (PCA)	0.750	PHEV-specific Factors	Battery Range (BR)	0.708
	Battery Recharging Time (BRT)	0.771		Public Charging Availability (PCA)	0.869
				Battery Warranty (BW)	0.704
Performance Factors	Engine Power (EP)	0.537	Performance Factors	Maximum Speed (MS)	0.752
	Acceleration Time (AT)	0.519		Engine Power (EP)	0.484
	Battery Range (BR)	0.712		Battery Recharging Time (BRT)	0.468
	Maximum Speed (MS)	0.562		Acceleration Time (AT)	0.683
	Battery Warranty (BW)	0.540		Tailpipe Emission (TE)	0.421
Goodness of Fit			Goodness of Fit		
TLI		0.970	TLI		0.971
CFI		0.985	CFI		0.984
RMSEA		0.044	RMSEA		0.034

speed, engine power, battery recharging time, acceleration time, and tailpipe emission.

4.3.2. Sensitivity analysis of EFA model

To assess the stability of the developed EFA models for Delhi and Kolkata, five-factor models were developed for several scenarios, each involving the exclusion of some observed variables. The factor models were then compared to the base model (shown in Table 6) in terms of variable loading onto a latent factor, factor loading of each variable, and goodness of fit indices. In total, six scenarios were constructed for sensitivity analysis of EFA models. For Delhi, in scenario 1, purchase cost was excluded due to its lowest factor loading on "monetary factors". Scenario 2 excluded advance vehicle technology (AVT) option, the attribute with lowest factor loading onto "pollution and safety aspects." Gadgets was excluded in scenario 3, representing the attribute with lowest factor loading on "aesthetics." Scenario 4 excluded public charging availability, the attribute with lowest factor loading on "charging components." Scenario 5 removed acceleration time, the attribute with lowest factor loading onto "performance factors." Finally, scenario 6 excluded all the variables corresponding to lowest factor loadings for latent factors namely purchase cost, AVT option, gadgets, public charging availability and acceleration time. A similar approach was adopted to construct scenarios for evaluating the stability of the developed EFA model for Kolkata. The results of the sensitivity analysis of EFA model for Delhi and Kolkata are presented in Table 7 and Table 8 respectively. The comparison of scenarios with the base model clearly reflects that even for different sets of observed variables, the variable loading onto a latent factor remains consistent, with the rotated factor loading values of ≥ 0.4 which indicates model stability and robustness. Also, for all the scenarios, the developed factor models show good model fit. Hence, the sensitivity analysis affirms the validity of the developed EFA models for Delhi and Kolkata and the reliability of the results obtained.

4.4. Final selection of attributes

This section presents GRA-based ranking of PHEV attributes for Delhi and Kolkata, sensitivity analysis of GRA model, and the selection of key attributes influencing PHEV choice based on EFA and GRA.

4.4.1. GRA-based ranking of attributes

For the identification of a small set of independent attributes to be used for designing stated preference experiment, GRA was used to rank the attributes loaded on each latent factor. It is important to mention that in EFA, higher loading of variables only indicates a strong association with the factor, it does not indicate higher priority of that variable based on consumer perception (Mitra et al., 2005). Hence, the most important variables were selected from each latent factor using GRA. The GRA-based ranking of PHEV attributes for Delhi and Kolkata is presented in Table 9.

In Delhi, safety ($\Gamma i = 0.877$) is ranked as the top-most important attribute. Battery warranty ($\Gamma i = 0.840$), seating comfort ($\Gamma i = 0.830$) and security ($\Gamma i = 0.829$) are ranked as second, third, and fourth most important attributes, respectively. Battery range ($\Gamma i = 0.824$), batter recharging time ($\Gamma i = 0.816$) and public charging availability ($\Gamma i = 0.813$) are the PHEV attributes perceived as the fifth, sixth, and seventh most important attributes, respectively by consumers in Delhi. Air conditioning ($\Gamma i = 0.798$) is ranked as eighth and purchase cost is ranked as ninth ($\Gamma i = 0.778$). Acceleration time ($\Gamma i = 0.668$), vehicle body type ($\Gamma i = 0.656$), resale value ($\Gamma i = 0.652$) and maximum speed ($\Gamma i = 0.572$) are perceived as the least important attributes. Similarly in Kolkata, safety ($\Gamma i = 0.868$) is ranked as the top-most important attribute. Tailpipe emission ($\Gamma i = 0.839$) is perceived as the second most important attribute. Public charging availability ($\Gamma i = 0.830$) and battery range ($\Gamma i = 0.827$) are ranked as third and fourth, respectively. Security ($\Gamma i = 0.822$) is ranked as fifth. Battery warranty ($\Gamma i = 0.815$) is perceived as the sixth most important attribute. Seating comfort ($\Gamma i = 0.803$), purchase cost ($\Gamma i = 0.752$) and air conditioning ($\Gamma i = 0.751$) are ranked as seventh, eighth, and ninth, respectively. Resale value ($\Gamma i = 0.646$), gadgets ($\Gamma i = 0.641$), acceleration time ($\Gamma i = 0.586$), and maximum speed ($\Gamma i = 0.546$) are ranked as the least important attributes from consumers' perspective.

4.4.2. Sensitivity analysis of GRA model

To test for the validity of the GRA-based ranking results, sensitivity analysis was conducted with respect to changing values of distinguishing coefficient (ξ). It is a significant issue whether changing the value of ξ impacts the ranking results, as it further influences the reliability and validity of the GRA method (Zolfani et al., 2022; Lo et al., 2021). Hence, the impact of changing values of ξ was examined over the ranking results. For sensitivity analysis, the value of ξ was changed from 0.5 in the base scenario to 0.3, 0.4, 0.6, and 0.7 for scenario 1, scenario 2, scenario 3, and scenario 4 respectively, and the corresponding values of average grey scores (Γi) and attribute rankings were evaluated for all scenarios. Fig. 2 and Fig. 3 present the plot of average grey scores of each attribute for different scenarios of ξ values for Delhi and Kolkata respectively. Further, Table 10 presents the ranking results for the evaluated scenarios.

It may be seen from Fig. 2 and Table 10, that for Delhi, the ranking position of safety, the top most important attribute, has not changed for different scenarios, with average grey scores varying from 0.838 for scenario 1 (i.e., the lowest value of$\xi = 0.3$) to 0.900 for scenario 4 (i.e., the highest value of$\xi = 0.7$). Similarly, for Kolkata, it may be seen from Fig. 3 and Table 10, the ranking of safety remains unchanged for all the scenarios, with average grey scores varying from 0.824 for scenario 1 (i.e., the lowest value of$\xi = 0.3$) to 0.894 for scenario 4 (i.e., the highest value of$\xi = 0.7$). For all the other attributes, the results may be interpreted in a similar manner. Hence, the consistency of the ranking results for most of the attributes clearly reflects that the GRA model has low sensitivity to the varying weights of distinguishing coefficient, which indicates model stability and robustness.

4.4.3. Selection of key attributes based on EFA and GRA

The key independent attributes influencing the adoption of PHEVs were obtained by selecting the attributes with the highest GRA-based ranking under each latent factor derived through EFA. The relevant attributes are outlined in Table 11. It may be observed from Table 11 that purchase cost, safety, air conditioning, battery recharging time, and battery warranty are identified as key attributes affecting the adoption of PHEVs in Delhi. On the other hand, for Kolkata, purchase cost, safety, air conditioning, public charging availability, and tailpipe emission are obtained as priority attributes influencing consumers' choice of PHEVs.

5. Key outcomes, discussion, and policy implications

Based on the study, the following sets of key outcomes can be presented with respect to key research questions or objectives of this work. The first research question investigates whether consumers' perception of PHEV attributes vary across cities. The results indicate a significant difference in consumer perception for several attributes across the two cities. The second research question explores whether consumers' perception of PHEV attributes varies across sociodemographic and trip-related groups within a city. The study indicates that the consumer perception towards PHEV attributes varies substantially among different sociodemographic and trip-related groups within a city. Lastly, the third research question investigates the latent factors influencing consumers' perception of PHEVs. The study identified five latent factors affecting PHEV adoption in both Delhi and Kolkata. Among these, "Monetary factors," "Aesthetics," and "Performance factors" emerged as a common set of factors influencing PHEV choice among the two cities. On the other hand, "Pollution and safety aspects" and "Charging components" were the two latent factors specific to Delhi, and "Safety-related factors"

Table 7
Sensitivity analysis of EFA model for Delhi.

Monetary Factors		Pollution and Safety Aspects		Aesthetics		Charging Components		Performance Factors	
Variable	Factor Loading	Variable	Factor Loading	Variable	Factor Loading	Variable	Factor Loading	Variable	Factor Loading
Scenario 1: Excluding purchase cost									
Gasoline/Diesel Range	0.580	Advance vehicle technology (AVT) option	0.487	Vehicle Body Type	0.665	Public Charging Availability	0.843	Engine Power	0.655
Fuel Cost	0.819	Safety	0.937	Gadgets	0.460	Battery Recharging Time	0.768	Acceleration Time	0.520
Maintenance Cost	0.651	Security	0.848	Appearance	0.709			Battery Range	0.717
Resale Value	0.481	Seating Comfort	0.655	Air Conditioning	0.571			Maximum Speed	0.576
		Tailpipe Emission	0.519					Battery Warranty	0.537
Goodness of Fit: TLI = 0.967, CFI = 0.984, RMSEA = 0.048									
Scenario 2: Excluding advance vehicle technology options									
Purchase Cost	0.482	Safety	0.935	Vehicle Body Type	0.613	Public Charging Availability	0.852	Engine Power	0.607
Gasoline/Diesel Range	0.614	Security	0.859	Gadgets	0.639	Battery Recharging Time	0.760	Acceleration Time	0.461
Fuel Cost	0.809	Seating Comfort	0.681	Appearance	0.508			Battery Range	0.710
Maintenance Cost	0.649	Tailpipe Emission	0.543	Air Conditioning	0.614			Maximum Speed	0.511
Resale Value	0.516							Battery Warranty	0.542
Goodness of Fit: TLI = 0.979, CFI = 0.990, RMSEA = 0.038									
Scenario 3: Excluding gadgets									
Purchase Cost	0.471	Advance vehicle technology (AVT) option	0.483	Vehicle Body Type	0.878	Public Charging Availability	0.858	Engine Power	0.561
Gasoline/Diesel Range	0.590	Safety	0.924	Appearance	0.588	Battery Recharging Time	0.733	Acceleration Time	0.534
Fuel Cost	0.808	Security	0.876	Air Conditioning	0.588			Battery Range	0.712
Maintenance Cost	0.639	Seating Comfort	0.688					Maximum Speed	0.492
Resale Value	0.508	Tailpipe Emission	0.542					Battery Warranty	0.536
Goodness of Fit: TLI = 0.970, CFI = 0.986, RMSEA = 0.045									
Scenario 4: Excluding public charging availability									
Purchase Cost	0.469	Advance vehicle technology (AVT) option	0.474	Vehicle Body Type	0.679	Battery Recharging Time	0.874	Engine Power	0.551
Gasoline/Diesel Range	0.595	Safety	0.938	Gadgets	0.478			Acceleration Time	0.509
Fuel Cost	0.801	Security	0.851	Appearance	0.725			Battery Range	0.607
Maintenance Cost	0.653	Seating Comfort	0.651	Air Conditioning	0.570			Maximum Speed	0.538
Resale Value	0.500	Tailpipe Emission	0.531					Battery Warranty	0.474
Goodness of Fit: TLI = 0.967, CFI = 0.984, RMSEA = 0.046									
Scenario 5: Excluding acceleration time									
Purchase Cost	0.452	Advance vehicle technology (AVT) option	0.447	Vehicle Body Type	0.599	Public Charging Availability	0.866	Engine Power	0.525
Gasoline/Diesel Range	0.758	Safety	0.941	Gadgets	0.515	Battery Recharging Time	0.728	Battery Range	0.711
Fuel Cost	0.772	Security	0.852	Appearance	0.945			Maximum Speed	0.715
Maintenance Cost	0.636	Seating Comfort	0.636	Air Conditioning	0.434			Battery Warranty	0.539
Resale Value	0.489	Tailpipe Emission	0.546						
Goodness of Fit: TLI = 0.967, CFI = 0.984, RMSEA = 0.046									
Scenario 6: Excluding purchase cost, advance vehicle technology option, gadgets, public charging availability and acceleration time									
Gasoline/Diesel Range	0.718	Safety	0.924	Vehicle Body Type	0.604	Battery Recharging Time	0.747	Engine Power	0.503
Fuel Cost	0.716	Security	0.886	Appearance	0.751			Battery Range	0.673
Maintenance Cost	0.892	Seating Comfort	0.519	Air Conditioning	0.522			Maximum Speed	0.728
Resale Value	0.473	Tailpipe Emission	0.527					Battery Warranty	0.521
Goodness of Fit: TLI = 0.989, CFI = 0.996, RMSEA = 0.031									

and "PHEV-specific factors" were the two latent factors specific to Kolkata. Subsequently, based on EFA and GRA, a key set of independent attributes affecting PHEV adoption was identified. A brief discussion on the identified key attributes and their relevance towards PHEV adoption in Indian context, irrespective of the city type are as follows:

Purchase Cost: Purchase cost is defined as the cost that the consumer pays to own a car and is found to be one of the most important attributes affecting PHEV choice decisions in the Indian context. The outcome corroborates past study findings, where initial purchase cost of EVs is found to be much more important for potential car buyers than savings on fuel cost (Hidrue et al., 2011; Carley et al., 2013; Haddadian et al., 2015). The purchase price of PHEVs is much higher as compared to conventional (gasoline or diesel) vehicles, primarily due to the high cost and size of battery used for vehicle propulsion (Helveston et al., 2015; Gong et al., 2020). Hence, in comparison to CVs, the high purchase cost of PHEVs could act as one of the primary barriers hindering PHEV choice among Indian consumers. In this regard, interventions by the government in terms of purchase subsidy can play a vital role towards attracting consumers to choose PHEV in the Indian context.

Safety: Safety is defined as ability of a car to reduce the risk of exposure to injuries during the event of an accident and is ranked as the top-most important attribute affecting consumer choice of PHEVs. The results contradict the prior research findings in India, where safety was ranked among the least significant attributes influencing car purchases (Mahapatra et al., 2010; Gupta, 2013). The findings may be attributed to the current scenario of road transport in the Indian context, where India tops the world in road crash deaths and injuries (Singh, 2017; Patil and Sharma, 2022). According to the 2021 report on road accident in India, there were 4,12,432 accidents leading to 1,53,972 fatalities and 3,84,448 injuries (Ministry of Road Transport and Highways (MoRTH), 2021). Hence, increased awareness of consumers about road safety could be responsible for the high priority placed on safety features in PHEVs. Car manufacturers should enhance safety features in PHEVs to increase their appeal among Indian consumers.

Air Conditioning: Air conditioning is defined as a system for controlling the humidity, ventilation, and temperature inside a car, and is observed to substantially influence consumers' PHEV buying behavior in the Indian context. The results obtained are contrary to the observations of past studies were air conditioning was identified as one of the least important attributes affecting consumers' car buying decisions (Banerjee and Pillania, 2009). India is experiencing a significant rise in temperature due to global warming and the consequent climate change (Rohini et al., 2016; Rao et al., 2020). The frequent episodes of extreme temperature conditions during the summer season over the Indian subcontinent could be the reason for high importance of air conditioning system in PHEVs. The car manufacturers should provide adequate air conditioning system inside the future generation PHEVs to enhance their attractiveness among Indian consumers.

Battery Recharging Time: Battery recharging time is defined as time taken to fully recharge the battery, and is identified to play a crucial role in consumer preference for PHEVs in the Indian context. The findings are in line with previous studies, where longer battery recharging time is identified as a significant barrier to faster adoption of EVs (Nie et al., 2018; Noel et al., 2019). The recharging/refueling time of EVs is substantially higher as compared to that of conventional cars, making it both time consuming and inconvenient for consumers (Qian et al., 2019; Li et al., 2020). Hence, car manufacturers are suggested to improve the battery recharging time of PHEVs to encourage wider diffusion of PHEVs in Indian megacities.

Battery Warranty: Battery warranty is defined as a type of guarantee that a manufacturer makes promising to repair or exchange the battery within a specified time period if it does not function as originally described or intended and is identified as an important attribute influencing consumers' PHEV purchase behavior in India. The results are aligned with past study findings, where battery warranty is found to have a substantial positive influence on consumer choice of EVs (Higgins et al., 2017; Li et al., 2020). Battery warranty is directly related to the electric vehicle kilometers of travel (e-VKT) delivered by a battery (Ambrose and Kendall, 2016; Li et al., 2020). Hence, high battery warranty would promise consumers with higher average annual e-VKT for PHEV usage. The car manufacturers should provide an added focus on battery warranty to attract consumers towards PHEV choice.

Public Charging Availability: Public charging availability is defined as density of public charging stations as compared to fuel stations and is found to substantially impact consumers' buying decisions of PHEVs in the Indian context. This is in line with the findings of previous studies, where limited charging infrastructure is identified as one of the major barriers towards widespread adoption of EVs (Tanaka et al., 2014; Higgins et al., 2017; Rommel and Sagebiel, 2021). In the current scenario, the availability of public charging station is very limited in India (Rajper and Albrecht, 2020). Hence, the inconvenience associated with waiting in a queue for long duration to recharge the vehicle could be responsible for higher importance of public charging availability among Indian consumers. The policymakers should focus on increasing the public charging availability for boosting the sales of PHEVs in India.

Tailpipe Emission: Tailpipe emission is defined as pollutants discharged from the tailpipe of a car such as CO_2, NO_x, SO_2, etc., and is found to be one of the most important attributes affecting PHEV adoption in the Indian context. The results corroborate past study findings, where reduction in tailpipe emission is found to be a strong driver towards the choice of EVs among consumers (Tanaka et al., 2014; Nie et al., 2018). The results logically relate to the current scenario of the worst air quality in India, where 48 % of the cities have PM2.5 concentrations greater than ten times the air quality guidelines set by WHO (IQAir, 2021). As a consequence, among the top 15 most polluted cities in the world, 12 cities are located in India. Air pollution is a serious problem and has adverse effects on human health (Mannucci and Franchini, 2017). The rising awareness among consumers regarding the public health risk associated with urban air pollution could be the reason for higher importance of tailpipe emissions in PHEVs. Hence, car manufacturers should focus on improving the emission reduction capabilities of PHEVs to make PHEVs a more appealing alternative to Indian consumers.

Like any other study, this study also has several limitations. First, the present study investigated the influence of several vehicle and infrastructure attributes on consumers' perception towards PHEVs. However, the effect of policy attributes such as purchase subsidy or rebate on upfront cost, purchase tax rebate/exemption, road tax rebate/exemption, free parking, access to high occupancy vehicle (HOV)/bus lane, free public charging stations, etc. on consumers' choice behavior of PHEVs were not explored. As a future scope of this research, it would be interesting to explore the influence of the aforementioned financial and non-financial policy attributes on consumers' perception towards PHEVs. Second, as a future scope of work, it would be interesting to conduct a heterogeneity study for micro-level classification of different sociodemographic and trip-related variables. Such an investigation would enable a comprehensive understanding of specific preferences within various population subgroups. Third, this study employed only GRA for ranking/prioritization of PHEV-related attributes based on consumers' importance rating responses. As a future extension of the work, other MCDM methods such as RIDIT and TOPSIS could be applied to the same database to compare the results and check the consistency of the results across the used methods. Fourth, although the identification of a key set of priority attributes provides useful information regarding consumer preference towards PHEVs, it also highlights the need to conduct future research, where the key attributes may be used for designing stated preference experiment for valuation of attributes in terms of willingness to pay and demand estimation of PHEVs by developing demand models. Moreover, the proposed methodology and broad findings may be used to formulate suitable policy suggestions for car manufacturers and the Government in other developed and developing countries to effectively promote PHEVs or other types of electric vehicles

Table 8
Sensitivity analysis of EFA model for Kolkata.

Monetary Factors		Safety-related Factors		Aesthetics		PHEV-specific Factors		Performance Factors	
Variable	Factor Loading	Variable	Factor Loading	Variable	Factor Loading	Variable	Factor Loading	Variable	Factor Loading
Scenario 1: Excluding gasoline/diesel range									
Purchase Cost	0.523	Advance vehicle technology (AVT) option	0.564	Vehicle Body Type	0.542	Battery Range	0.702	Maximum Speed	0.746
Fuel Cost	0.798	Safety	0.907	Appearance	0.581	Public Charging Availability	0.871	Engine Power	0.485
Maintenance Cost	0.610	Security	0.782	Air Conditioning	0.438	Battery Warranty	0.705	Battery Recharging Time	0.462
		Seating Comfort	0.472					Acceleration Time	0.701
		Gadgets	0.420					Tailpipe Emission	0.401
Goodness of Fit: TLI = 0.968, CFI = 0.983, RMSEA = 0.037									
Scenario 2: Excluding gadgets									
Purchase Cost	0.515	AVT option	0.516	Vehicle Body Type	0.541	Battery Range	0.709	Maximum Speed	0.762
Gasoline/Diesel Range	0.460	Safety	0.898	Appearance	0.507	Public Charging Availability	0.871	Engine Power	0.485
Fuel Cost	0.839	Security	0.805	Air Conditioning	0.431	Battery Warranty	0.701	Battery Recharging Time	0.464
Maintenance Cost	0.596	Seating Comfort	0.496					Acceleration Time	0.678
								Tailpipe Emission	0.411
Goodness of Fit: TLI = 0.987, CFI = 0.993, RMSEA = 0.024									
Scenario 3: Excluding air conditioning									
Purchase Cost	0.509	AVT option	0.564	Vehicle Body Type	0.535	Battery Range	0.704	Maximum Speed	0.739
Gasoline/Diesel Range	0.407	Safety	0.882	Appearance	0.522	Public Charging Availability	0.881	Engine Power	0.498
Fuel Cost	0.827	Security	0.798			Battery Warranty	0.699	Battery Recharging Time	0.461
Maintenance Cost	0.603	Seating Comfort	0.483					Acceleration Time	0.691
		Gadgets	0.440					Tailpipe Emission	0.404
Goodness of Fit: TLI = 0.974, CFI = 0.987, RMSEA = 0.033									
Scenario 4: Excluding battery warranty									
Purchase Cost	0.508	AVT option	0.560	Vehicle Body Type	0.534	Battery Range	0.769	Maximum Speed	0.757
Gasoline/Diesel Range	0.402	Safety	0.883	Appearance	0.531	Public Charging Availability	0.791	Engine Power	0.480
Fuel Cost	0.844	Security	0.809	Air Conditioning	0.429			Battery Recharging Time	0.490
Maintenance Cost	0.594	Seating Comfort	0.486					Acceleration Time	0.678
		Gadgets	0.425					Tailpipe Emission	0.429
Goodness of Fit: TLI = 0.967, CFI = 0.983, RMSEA = 0.037									
Scenario 5: Excluding tailpipe emission									
Purchase Cost	0.512	AVT option	0.565	Vehicle Body Type	0.530	Battery Range	0.707	Maximum Speed	0.749
Gasoline/Diesel Range	0.406	Safety	0.887	Appearance	0.529	Public Charging Availability	0.869	Engine Power	0.483

(*continued on next page*)

Table 8 (*continued*)

Monetary Factors		Safety-related Factors		Aesthetics		PHEV-specific Factors		Performance Factors	
Variable	Factor Loading	Variable	Factor Loading	Variable	Factor Loading	Variable	Factor Loading	Variable	Factor Loading
Fuel Cost	0.823	Security	0.795	Air Conditioning	0.416	Battery Warranty	0.702	Battery Recharging Time	0.475
Maintenance Cost	0.605	Seating Comfort	0.487					Acceleration Time	0.683
		Gadgets	0.423						
Goodness of Fit: TLI = 0.967, CFI = 0.983, RMSEA = 0.038									
Scenario 6: Excluding gasoline/diesel range, gadgets, air conditioning, battery warranty and tailpipe emission									
Purchase Cost	0.523	AVT option	0.507	Vehicle Body Type	0.598	Battery Range	0.765	Maximum Speed	0.731
Fuel Cost	0.816	Safety	0.903	Appearance	0.678	Public Charging Availability	0.800	Engine Power	0.505
Maintenance Cost	0.603	Security	0.820					Battery Recharging Time	0.498
		Seating Comfort	0.500					Acceleration Time	0.708
Goodness of Fit: TLI = 0.983, CFI = 0.993, RMSEA = 0.028									

Table 9
Ranking of attributes using GRA.

Attribute	Delhi		Kolkata	
	Avg. Grey Score (Γi)	Rank	Avg. Grey Score (Γi)	Rank
Purchase Cost (PC)	0.778	9	0.752	8
Fuel Type (FT)	0.707	18	0.702	14
Advance Vehicle Technology (AVT) option	0.722	14	0.705	12
Gasoline/Diesel Range (GDR)	0.709	17	0.715	11
Fuel Cost (FC)	0.746	12	0.750	10
Maintenance Cost (MC)	0.710	16	0.699	15
Battery Range (BR)	0.824	5	0.827	4
Gadgets (GG)	0.716	15	0.641	20
Appearance (AP)	0.768	11	0.696	16
Tailpipe Emission (TE)	0.774	10	0.839	2
Air Conditioning (AC)	0.798	8	0.751	9
Battery Warranty (BW)	0.840	2	0.815	6
Resale Value (RV)	0.652	21	0.646	19
Safety (SF)	0.877	1	0.868	1
Security (SR)	0.829	4	0.822	5
Engine Power (EP)	0.744	13	0.704	13
Battery Recharging Time (BRT)	0.816	6	0.677	17
Acceleration Time (AT)	0.668	19	0.586	21
Maximum Speed (MS)	0.572	22	0.546	22
Public Charging Availability (PCA)	0.813	7	0.830	3
Vehicle Body Type (VBT)	0.656	20	0.649	18
Seating Comfort (SC)	0.830	3	0.803	7

in urban areas.

6. Conclusion

The results derived from this study unveil several interesting findings. The investigation of consumer perception in two Indian megacities, namely Delhi and Kolkata indicate a significant difference in perception for several Plug-in Hybrid Electric Vehicle (PHEV) attributes (e.g. purchase cost, advance vehicle technology option, battery range, gadgets, appearance, tailpipe emission, air conditioning, engine power, battery recharging time, acceleration time, maximum speed, and seating comfort) across the two cities. The results indicate that the requirements of PHEV and related attributes are expected to vary across the two cities as per the city context. Hence, it is crucial to consider city characteristics and the respective consumers' perspectives when devising marketing strategies to boost the adoption of PHEVs. Further, within city heterogeneity study reveals a significant difference in perception for PHEV attributes across consumers with different sociodemographic (e.g., gender, age, education, monthly household income, car ownership, vehicle body type owned, and garage availability) and trip-related characteristics (e.g., average commuting distance). The results reveal a strong influence of sociodemographic and trip-related characteristics on consumer preference for PHEVs. By acknowledging such differences in consumer perception within a city, policymakers can develop more nuanced and targeted strategies that cater to the specific needs of diverse consumer segments.

The evidence of both between cities and within a city heterogeneity justified the development of separate exploratory factor models for Delhi and Kolkata. The analysis derived five-factor model for both Delhi and Kolkata. "Monetary factors," "Aesthetics," and "Performance factors" were the common set of latent factors obtained for both cities. On the other hand, "Pollution and safety aspects" and "Charging components" were the two latent factors specific to Delhi, and "Safety-related factors" and "PHEV-specific factors" were the two latent factors specific to Kolkata. Interestingly, in Delhi, battery recharging time and public charging availability are loaded onto the latent factor "Charging component," which may be ascribed to the absence of garage availability for charging outlets for most of the consumers in Delhi, but in

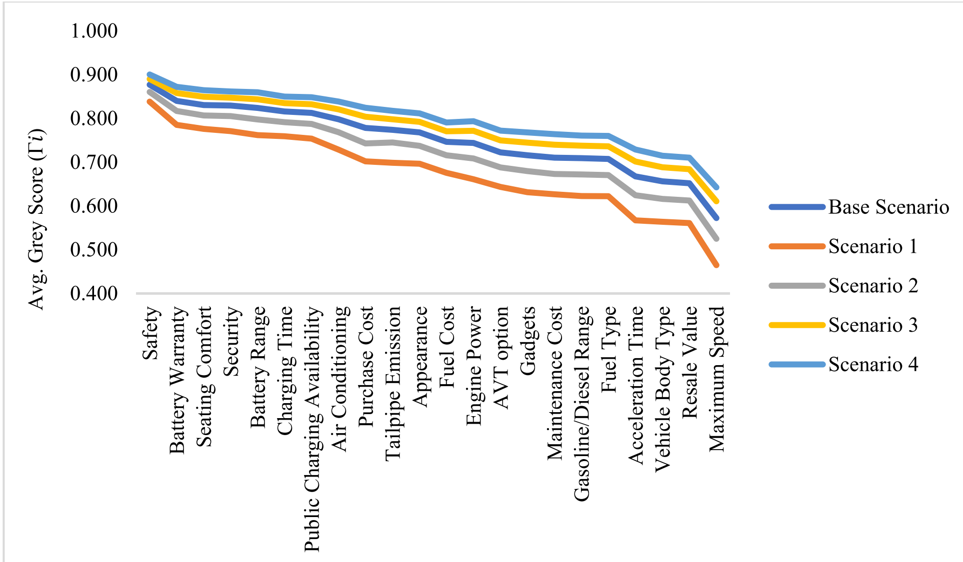

Fig. 2. Average grey score of each attribute for ξ values between 0.7 ≤ ξ ≤ 0.3 for Delhi.

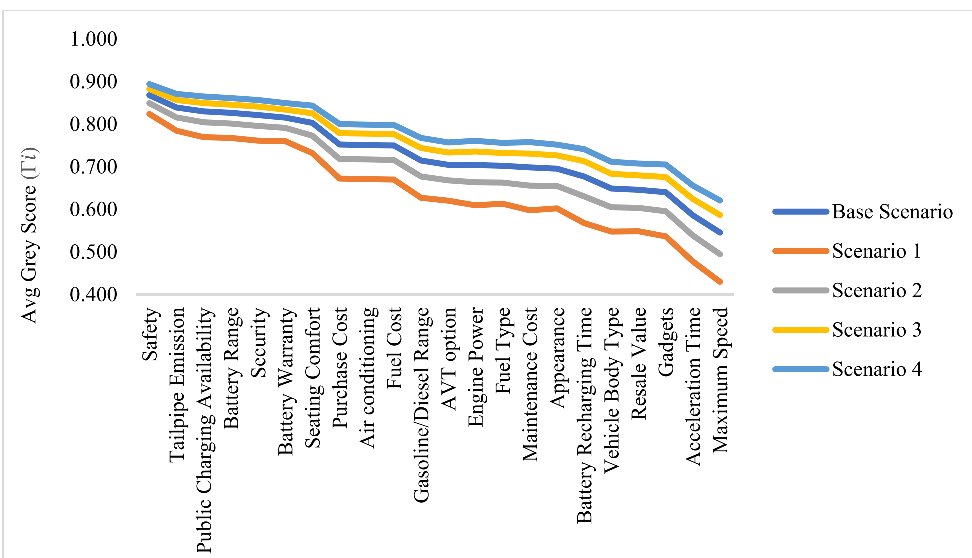

Fig. 3. Average grey score of each attribute for ξ values between 0.7 ≤ ξ ≤ 0.3 for Kolkata.

Kolkata, battery recharging time is loaded onto the latent factor "Performance factors," and public charging availability is loaded into the latent factor "PHEV-specific factors." Such differential loading of variables indicates city-specific influence on consumer perception and concern towards PHEV-related attributes. Based on the ranking of attributes derived using Grey Relation Analysis (GRA), safety is identified as the topmost important attribute influencing consumer perception of PHEV adoption in both cities. As India records the highest road fatality, the requirement of enhanced vehicle safety is extremely meaningful as it reflects the growing awareness of car owners towards safety. On the other hand, resale value, acceleration time, and maximum speed are identified as the least important attributes for PHEV choice. Finally, based on EFA and GRA, purchase cost, safety, air conditioning, battery warranty, public charging availability, battery recharging time, and tailpipe emission are identified as the key attributes affecting the adoption of PHEVs in the Indian context. The high purchase price of PHEVs as compared to conventional vehicles could act as one of the primary deterrents towards PHEV choice among Indian consumers. Also, in India, the limited availability of public charging stations in the current scenario could be a major concern among consumers due to the associated long waiting time in a queue for recharging the vehicle. In this regard, interventions by the government in terms of purchase subsidy and increase in public charging availability would play a vital role towards boosting the sales of PHEVs in India. The car manufacturers on the other hand should focus on improving the vehicle features such as safety, air conditioning, battery recharging time, battery warranty, and tailpipe emission capabilities of PHEVs to make PHEVs a more attractive alternative to Indian consumers.

CRediT authorship contribution statement

Reema Bera Sharma: Conceptualization, Methodology, Validation, Formal analysis, Investigation, Writing – original draft, Visualization. **Bhargab Maitra:** Conceptualization, Methodology, Resources, Writing – review & editing, Supervision, Project administration, Funding acquisition.

Table 10
Ranking results for different values of distinguishing coefficient (ξ) for Delhi and Kolkata.

Attribute	Delhi					Attribute	Kolkata				
	Base Scenario ($\xi = 0.5$)	Scenario 1 ($\xi = 0.3$)	Scenario 2 ($\xi = 0.4$)	Scenario 3 ($\xi = 0.6$)	Scenario 4 ($\xi = 0.7$)		Base Scenario ($\xi = 0.5$)	Scenario 1 ($\xi = 0.3$)	Scenario 2 ($\xi = 0.4$)	Scenario 3 ($\xi = 0.6$)	Scenario 4 ($\xi = 0.7$)
Safety (SF)	1	1	1	1	1	Safety (SF)	1	1	1	1	1
Battery Warranty (BW)	2	2	2	2	2	Tailpipe Emission (TE)	2	2	2	2	2
Seating Comfort (SC)	3	3	3	3	3	Public Charging Availability (PCA)	3	3	3	3	3
Security (SR)	4	4	4	4	4	Battery Range (BR)	4	4	4	4	4
Battery Range (BR)	5	5	5	5	5	Security (SR)	5	5	5	5	5
Battery Recharging Time (BRT)	6	6	6	6	6	Battery Warranty (BW)	6	6	6	6	6
Public Charging Availability (PCA)	7	7	7	7	7	Seating Comfort (SC)	7	7	7	7	7
Air Conditioning (AC)	8	8	8	8	8	Purchase Cost (PC)	8	8	8	8	8
Purchase Cost (PC)	9	9	10	9	9	Air Conditioning (AC)	9	9	9	9	9
Tailpipe Emission (TE)	10	10	9	10	10	Fuel Cost (FC)	10	10	10	10	10
Appearance (AP)	11	11	11	11	11	Gasoline/Diesel Range (GDR)	11	11	11	11	11
Fuel Cost (FC)	12	12	12	13	13	Advance Vehicle Technology option (AVT)	12	12	12	13	14
Engine Power (EP)	13	13	13	12	12	Engine Power (EP)	13	14	13	12	12
Advance Vehicle Technology (AVT) option	14	14	14	14	14	Fuel Type (FT)	14	13	14	14	15
Gadgets (GG)	15	15	15	15	15	Maintenance Cost (MC)	15	16	15	15	13
Maintenance Cost (MC)	16	16	16	16	16	Appearance (AP)	16	15	16	16	16
Gasoline/Diesel Range (GDR)	17	17	17	17	17	Battery Recharging Time (BRT)	17	17	17	17	17
Fuel Type (FT)	18	18	18	18	18	Vehicle Body Type (VBT)	18	18	18	18	18
Acceleration Time (AT)	19	19	19	19	19	Resale Value (RV)	19	19	19	19	19
Vehicle Body Type (VBT)	20	20	20	20	20	Gadgets (GG)	20	20	20	20	20
Resale Value (RV)	21	21	21	21	21	Acceleration Time (AT)	21	21	21	21	21
Maximum Speed (MS)	22	22	22	22	22	Maximum Speed (MS)	22	22	22	22	22

Table 11
Selected set of attributes based on combined EFA and GRA.

Latent factor	Attributes with highest GRA ranking
Delhi	
Monetary Factors	Purchase Cost
Pollution and Safety Aspects	Safety
Aesthetics	Air Conditioning
Charging Components	Battery Recharging Time
Performance Factors	Battery Warranty
Kolkata	
Monetary Factors	Purchase Cost
Safety-related Factors	Safety
Aesthetics	Air Conditioning
PHEV-specific Factors	Public Charging Availability
Performance Factors	Tailpipe Emission

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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