Technological Forecasting & Social Change 167 (2021) 120738

Contents lists available at ScienceDirect

Technological Forecasting & Social Change

journal homepage: www.elsevier.com/locate/techfore

Enhancement of electric vehicles' market competitiveness using fuzzy quality function deployment

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ARTICLE INFO

Keywords:
Multi regression method
Fuzzy quality function deployment
Electric mobility
Market analysis

ABSTRACT

The rising level of carbon emissions has plunged the world into global warming. These emissions originate from different sectors however, one of the major contributions comes from the transportation sector. In order to tackle this problem, greener modes of transportation like Electric Vehicles (EV) are introduced as an alternative option. Currently, different types of EVs are available in the market, with Hybrid Electric Vehicles (HEV) being the most popular type of EV in developing countries. Nevertheless, a lot of customers are still preferring Conventional Vehicles (CV) over EVs, which is inevitably damaging the market share of EVs and creating problems in their wider acceptance. Thus, the aim of this study is to solve two problems. First, to identify the factors which make CVs more appealing to the customers. Secondly, how these shortcomings can be overcome for HEVs. For this purpose, the relationship of different parameters with CVs is evaluated using the multiple regression method, which is then incorporated into the Fuzzy Quality Function Deployment (FQFD) model to find the best solution for adding those parameters to HEVs. The analysis resulted in the identification of affordability, reliability, variety and fuel consumption as the key contributors that made CVs, a more attractive option to the customers. Furthermore, local manufacturing was identified as the best solution for improving the quality of HEVs and make them market competitive in developing countries. The practical applications of this research, along with the contextual analysis of the developing countries are the principal novelties of the study.

1. Introduction

Global warming is a worldwide phenomenon, that is causing shifts in the natural balance of the Earth's ecosystem. The effects of these shifts are being felt around the world in the form of melting glaciers, severe droughts and an increase in forest wildfires. Furthermore, sea levels are also rising, which has increased the chances of floods and has resulted in the disruption of the natural weather cycles. Consequently, putting many habitats and species at the risk of extinction (Perera, 2017). Scientists are warning the masses about the consequences and the impact, global warming will have on the environment, economy, and health if the current trend is continued. The root of global warming is the increase in environmental pollution, which is caused by the release of carbon emissions into the open environment. These emissions and other toxic wastes are generated from the burning and overuse of fossil fuels.

Fossil fuels are a non-renewable form of natural resource, which are used for the generation of energy through the process of combustion. During this process, carbon dioxide (CO_2), carbon monoxide (CO) and other toxic gasses are produced as by-products. The gasses, when released into the air cause the greenhouse effect, which results in the depletion of the ozone layer, heating of the Earth's temperature and ultimately results in global warming (Perera, 2018). These gasses are emitted from different sources but one of the greatest contributions comes from the transport sector. Almost 20.9 percent of the total carbon emission comes from the transportation sector (Worldometers, 2020). The reason for such a high percentage is the heavy reliance on fossil fuels for the operation of vehicles. Moreover, for the most part, no suitable alternative was present that used renewable sources of energy. However, with the advancement of technology, electric vehicles were introduced as alternatives into the market for purchase.

Electric vehicles are greener mode of transportation, as it operates on electricity that could be generated from renewable energy sources. Currently, different variations of electric vehicles are available in the market. The most common types of electric vehicles include full electric vehicles, hybrid vehicles that have electric batteries along with small combustion engines and those transports that are using hydrogen fuel cell technology. All of these are electronically driven vehicles that are replacing old combustion vehicles in the market (Herrmann and

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https://doi.org/10.1016/j.techfore.2021.120738
Received 26 October 2020; Received in revised form 1 March 2021; Accepted 6 March 2021
Available online 13 March 2021

Rothfuss, 2015).

Depending on the economic and technological capabilities, countries around the world are shifting towards electric vehicles. Most of the developed countries like the USA, UK and other European countries have measures and policies in place to shift their entire transportation fleet from combustion vehicles to electric vehicles. European Union has planned to reduce its carbon emissions by 12 percent by 2021 through the introduction of electric vehicles and completely shift to greener transportation by 2030 (European Commission, 2013). Similarly, developing countries like Bangladesh, Sri Lanka, China, etc. are also making a shift towards electric vehicles to reduce the carbon emissions in their country. These countries have emerging economies and they are rapidly industrializing, which has increased the problem of pollution and smog in these countries. To tackle this problem and reduce their carbon footprint, they have devised policies and planes to transform their entire transportation fleets to EVs. The prime example of such measures is India, which is another emerging country in South-East Asia, that has planned to convert all conventional vehicles to EVs by 2030 (Das et al., 2019). Like its neighboring countries, Pakistan is also a developing country, that is facing problems from the carbon emission in the form of increasing smog, health issues and loss of capital due to huge imports of fossil fuels (Ali et al., 2019). To tackle the problem, Pakistan is also making a shift towards full electric vehicles. However, unlike the other countries, Pakistan lacks the technological and economic proficiency to make the shift.

Different studies have been conducted to check the feasibility of electric vehicles in Pakistan. According to these researches, despite the lack of economic and technological capabilities, Pakistan can still shift towards electric vehicles by introducing hybrid electric vehicles as prime compotators to combustion vehicles (Babar et al., 2020). The reason, hybrid electric vehicles are most suitable for Pakistan's socio-economic culture is its lack of prerequisites, that are required by other electric vehicles. Hybrid electric vehicles don't require huge economy and technology aptitude, as it doesn't have needs like infrastructure needs, an abundance of electricity supply, renewable power sources or other technological needs as full electric vehicles, thus making it perfect choice for Pakistan. However, despite being a more viable option in the Pakistani market, hybrid electric vehicles still do not come close to competing with combustion vehicles. People in Pakistan are still opting for conventional vehicles, which has created a huge problem for the electric vehicles market in Pakistan. Furthermore, if nothing is done about the situation, electric vehicles might disappear from the Pakistani Market, due to a lack of sales (The News, 2020).

The study addresses the aforementioned problem by finding the factors that make combustion vehicles more appealing to the customers in the Pakistani Market. Furthermore, the research also instructs on, how the shortcomings can be overcome for hybrid electric vehicles and make them more alluring to the customers in the best possible manner.

Two methods are used in this study, for improving the market compatibility of hybrid electric vehicles in Pakistan. Firstly, Multi Regression Analysis (MRA) is used to find the relationship between different parameters (like affordability, mileage, aesthetics, etc.) with customer fondness for combustion vehicles. The results obtained from multiple regression are then translated into the Fuzzy Quality Function Deployment (FQFD) model. The customers' preferences become WHATs in the model. At the same time, the different technical specifications also called HOWs, are explored for hybrid electric vehicles, in order to find the best method to achieve those preferences. FQFD results in methods, that could be used to improve multiple qualities of hybrid electric vehicles and make them market competitive.

The rest of the paper is organized as follows. In Section 2, the literature review is discussed at length, which gives further knowledge of electric vehicles and the techniques used. In Section 3, the methodology of using the techniques is explained. In Section 4, the process of data collection is discussed. Lastly, in Section 5 the results are discussed and the conclusion is drawn in Section 6.

2. Literature review

The literature on Electric Vehicles (EV) suggests that EVs are not only greener and environmental-friendly, they are also more economical, as compare to combustion vehicles (Faria et al., 2012). One of the first studies to calculate the lifetime cost of EV through technical and economic assessments shows that EV is more economical in the long run (Delucchi and Lipman, 2001). Similarly, another study shows that the operation cost of EVs is lower than the conventional vehicles, which further solidifies the superiority of EVs (Propfe et al., 2012). However, despite the low total cost of ownership of EVs, more recent studies have identified that customers purchasing intentions are not solely driven by the cost factors (Wu et al., 2015). Other aspects also play a vital role, which explains the low market shares for electric vehicles as compared to combustion vehicles (Heffner et al., 2007).

The current market status of EV might not look promising, but multiple pieces of research back the notion, that one day EV will completely dominate the market. The majority of such studies are mentioned in the review paper along with past to present market assessments (Pollet et al., 2012). The market for EVs can be improved by placing proper standards for the development of EVs and following certain protocols, that will ensure the smooth transition to EV in order to reduce carbon footprint (Brown et al., 2010). EV shares can further be improved by analyzing the market and finding the basis for customer satisfaction and identifying the reasons for the rejection of vehicles. The most cited reasons for the rejection of EVs are price and value (Jabbari et al., 2017). All of the literature to date shows that EVs are a viable replacement option for conventional vehicles (CV). However, they can't compete in the market as people choose CV over EV. Nearly all of the studies talk about different individual factors that could be a reason for the market incompetence of EVs. Though not a single study comprehensively assesses all the factors and devise a plan on how to incorporate the most important factors in EVs, in order to make them more competitive in the market. Therefore, this study has undertaken the task to fulfill the following research gap by analyzing the factors and short-listing the ones that could make a significant change in the customers' preferences.

Through the panel regression model, the link between the total cost of ownership and market share is analyzed for EVs in the United Kingdom (UK), United States of America (USA) and Japan. The results show that hybrid electric vehicles are the most popular types of EVs among the customers and occupy the highest market shares in UK, USA and Japan (Palmer et al., 2018). Similarly, in our neighboring country China, EVs are also gaining a huge market share in the form of electric two-wheelers (Weinert et al., 2008). Similarly, in India, different policies are recommended for the adaption of EVs as a sustainable mode of transportation (Srikanth, 2018). In Pakistan, EVs are also penetrating the market in the form of hybrid electric vehicles. Even though EVs are in their earliest stages, recent market analysis shows that hybrid electric vehicles can become a prime contender to combustion vehicles in the near future (Khan et al., 2020). One such indication is the design and analysis of hybrid power rickshaws that could be used for commercial purposes in Pakistan (Saleh et al., 2016).

Multi Regression Analysis (MRA) is the first technique that has been used in this paper for finding the relationship between the dependent and various independent variables. The use of this technique in research dates back to, as late as the 1800s (Allen, 2004). It has been used in different studies in its various forms. More recently it has been used in the creation of WinMLR software. The software determines several components in a mixture simultaneously through the use of multi regression (Becerra et al., 2020). The same technique is also used of surface sediment obtained from the contaminated lagoon, in order to assess the spatial distribution and the type of mercury in it (Stoichev et al., 2019). Similarly, MRA is also used for the optimization of working conditions for the perovskite-based gas sensor in order to increase their sustainability (Zaza et al., 2019). One study predicts the poor outcome of

recanalization through the use of the same technique on the NASA registry (Linfante et al., 2016). MRA has also been used in the study of EVs and customer behavior patterns. The technique is used in assessing the relationship of energy consumption on speed and acceleration of EV, while also checking its implications on drivers and policymakers (Galvin, 2017). Furthermore, in Norway, the impact of EVs on vehicle purchase and driving behavior of customers is checked using a type of multi regression called logistic regression (Bauer, 2018). Hierarchical regression analysis is another type of multi regression tool, that has been used to find the impact of different factors of EVs on behavioral preferences in the Nordic countries (Chen et al., 2020). In Pakistan, the linear regression approach is used to evaluate the impact of green supply chain management on industrial performance (Mumtaz et al., 2018).

The second technique used in this study is Fuzzy Quality Function Deployment (FQFD). It is used to translate customer's voices into product value in a fuzzy environment. The use of Quality Function Deployment (QFD) in research can also be traced back to, as late as the 1960s. However, in modern research, a lot of variations of QFD can be found, where a hybrid MCDM (Multi-Criteria Decision Making) based QFD or FQFD approach is applied to get results. One such study integrates QFD with the DEMATEL technique from MCDM, for the selection of green suppliers (Yazdani et al., 2017). Another study integrates QFD with Pythagorean Fuzzy Set for improving sustainable supply chain management and removing the fuzziness of human thoughts in decision making (Büyüközkan and Çifçi, 2019). Other MCDM techniques like AHP and TOPSIS are used with hesitant FQFD to find the relationship between customer requirements and design requirements for the selection of computer workstations (Çevik Onar, et al., 2016). AHP based QFD is applied for evaluating different options of onboard photovoltaic modules that are used in EVs (Abdelhamid et al., 2014). In another study, hesitant FQFD is integrated with MCDM, namely DEMATEL and VIKOR techniques, in order to find the interrelationship between different customer requirements and engineering characteristics of EVs (Wu et al., 2016). Some of the more recent studies on MCDM are given in Table 1.

Similar to the studies mentioned above, the application of QFD can also be found in the Pakistani context. The theory of constraints and QFD is used with the Delphi method, in order to improve the quality of higher education in Pakistan and raise it to international standards (Qureshi et al., 2014). QFD strategy is also used to improve the customer satisfaction levels in telecom companies of Pakistan (Hussain et al., 2011). Similarly, QFD also finds extensive application in modern technological design and development research. Spherical FQFD is applied in the development of linear delta robot technology (Kutlu Gündoğdu and Kahraman, 2020). For the design and development of the smart bicycle, heterogeneous information is integrated with QFD to arrive at a result (Büyüközkan et al., 2020).

The novelty of the study is the practical application of hybrid method consisting of MRA and FQFD techniques, to analyze the real-world problem of EV's market share, especially from the perspective of developing nations. From the above literature, it can be seen that the regression method is widely used for forecasting and finding the causal relationship between dependent variables and independent variables. In our case, dependent variables are customer's preferences and independent variables are the different parameters. The results of which are then used in Fuzzy Quality Function Deployment (FQFD). QFD is a tool, that is used to transform the voice of the customer into engineering characteristics for a product. Similarly, in this study, it is used to transform customer wants into product value for hybrid electric vehicles. Thus, making these two methods most suited for conducting this research. Furthermore, neither of the techniques have been applied to the automobile sector and used for evaluating the preferences of the customers in such a unique manner. Thus, the use of hybrid technique and the case study of EVs from a developing country's perspective, are the prime contributions of the research study.

Table 1.
Recent Studies based on MCDM.

Title of the Study	Aim and Objective of the Study	Reference
Sustainable supplier selection using combined FUCOM – Rough SAW model	FUCOM based Rough SAW method is used to create a sustainable supply chain through appropriate selection of a supplier.	(Durmić et al., 2020)
A hybridized IT2FS-DEMATEL-AHP-TOPSIS multicriteria decision making approach: Case study of selection and evaluation of criteria for determination of air traffic control radar position	A hybridized IT2FS-DEMATEL-AHP-TOPSIS method is used to for determining the position of radar for better air traffic management.	(Petrovic and Kankaras, 2020)
Prioritizing the Weights of The Evaluation Criteria Under Fuzziness: The Fuzzy Full Consistency Method – Fucom-F	Introduced a novel Fuzzy FUCOM technique for determining weight in a fuzzy environment.	(Pamucar and Ecer, 2020)
An approach to rank picture fuzzy numbers for decision making problems	A novel method is introduced for comparing the Picture Fuzzy Numbers (PFN) when the value and scores are equal.	(Si et al., 2019)
A Novel Multi-Criteria Decision-Making Model: Interval Rough SAW Method for Sustainable Supplier Selection	MCDM technique named Interval Rough SAW method was developed for the selection of sustainable supplier.	(Stević et al., 2019)
Prioritizing mechanism of low carbon shipping measures using a combination of FQFD and FTOPSIS	Fuzzy QFD is used with Fuzzy TOPSIS to prioritize the best low carbon shipping measures required by the shipping stakeholders.	(Wang and Nguyen, 2017)
A hybrid multi-criteria decision-making approach to assess the enablers of manufacturing flexibility under fuzzy environment	Hybrid technique consisting of Fuzzy QFD, Fuzzy AHP and Fuzzy TOPSIS is used to priorities the enablers of manufacturing flexibility.	(Mishra, 2020)
Assessment of workplace accident risks in underground collieries by integrating a multi-goal cause-and-effect analysis method with MCDM sensitivity analysis	Accidents risks in the workplace of underground collieries are analyzed using cause and effect method, along with MCDM and sensitivity analysis.	(Bakhtavar and Yousefi, 2018)
Optimal Selection of Electric Motor for E-Rickshaw Application Using MCDM Tools	TOPSIS and DEMATEL techniques are used for the selection of the optimal electric motor for e-rickshaw in India.	(Anand et al., 2020)
Study on location decision framework of electric vehicle battery swapping station: Using a hybrid MCDM method	MCDM techniques are used to create a framework for making location decisions for electric vehicles battery swapping stations.	(Wang et al., 2020)

3. Methodology

Two techniques are proposed in this paper. The first technique is Multi Regression Analysis (MRA). It is used to find the relationship between different independent variables, with the dependent variable. Based on the results obtained from multi regression, the variables that have a significant amount of variances are selected. These independent variables are then used in the Fuzzy Quality Function Deployment (FQFD) model, which is the second technique used in this study. The selected variables are translated as WHAT in the model and their relationship with different engineering methods (HOWs) are evaluated. Based on the evaluation, the HOWs are ranked and the one with the highest rank is selected as the final solution. The detailed methodology of both the techniques is given below, while a visual overview is given in Fig. 1.

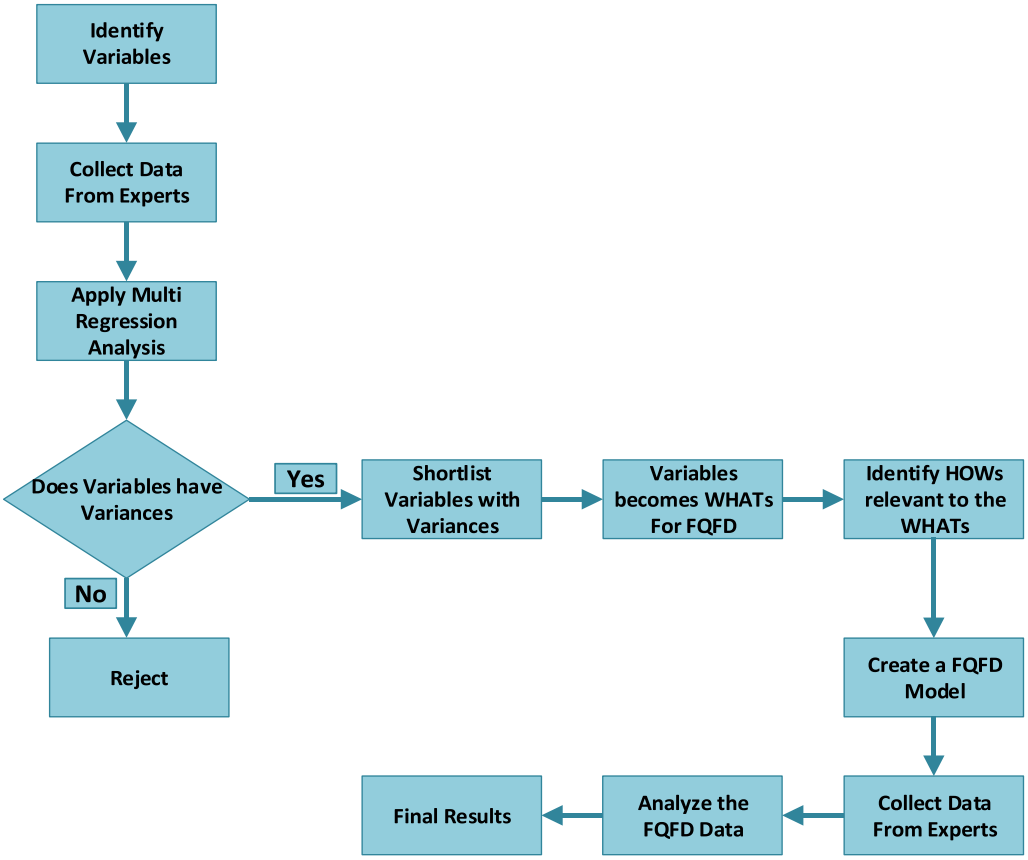

Fig. 1. Pictorial Overview of Methodology (Authors own constructed).

3.1. Multi regression analysis

The following steps are followed in this technique

Step 1: Firstly, all the different attributes that influence the customer's selection process at the time of vehicle purchase are identified. These variables are termed as independent variables (X_i) in the analysis, while the probability of selecting a combustion vehicle over EV is termed as dependent variable (Y) in the regression analysis.
Step 2: Data for the independent variables and the dependent variable is collected through the process mentioned in Section 4.
Step 3: After the data is collected. MRA is performed to check the relationship between the dependent variable and independent variable with the help of the following equation:

$$Y = \beta_o + \beta_1 X_1 + \beta_2 X_2 + \cdots + \beta_n X_n \quad (1)$$

where, β_o is the slope-intercept and $\beta_1, \beta_2, \cdots, \beta_n$ are the slope of the regression line.

Step 4: Next, find R^2 also known as the coefficient of determination, in order to check the regression relationship, using the following equation.

$$R^2 = \frac{SSR}{SST} \quad (2)$$

where, SSR is the sum of squares due to regression and SST is the sum of squares due to error.

Step 5: Create null hypothesis (H_0) and the alternative hypothesis (H_a) for variances of all variables. Then calculate the overall level of significance and individual level of significance between dependent and independent variables, using F statistical and t statistical tests. It should be noted, that all of these analyses could be easily performed using the 'Data Analysis' tool in excel.
Step 6: Based on the level of significance accept or reject the null hypothesis (H_0). For variables, that have a p-value lower than the significance level (α), we will reject H_0 and accept the alternative hypothesis, as these variables would have a significant amount of variance that could influence the outcome. The vice versa would be true for the variables, that have a p-value greater than or equal to the significance level (α). In this case, we will accept H_0 and reject the alternative hypothesis.

3.2. Fuzzy quality function deployment (FQFD)

After the results are obtained from MRA, we move to the FQFD model. The following steps are followed for the application of this technique.

Step 1: The independent variables, for which H_0 is rejected in MRA. We would accept those variables or attributes and translate them as customer requirements (WHAT) in the FQFD model. The reason behind the selection of only such variables is the high values of R^2, variance and level of significance. In other words, these values indicate the importance and the influence these variables have on the dependent variable.
Step 2: After the WHAT is identified. The next step is to find ways in which the customer requirements could be transform into product value using certain engineering approaches, also known as HOWs. The HOWs are identified using the steps mentioned in Section 4.

Step 3: Based on the WHATs and HOWs, an FQFD model is created and dispatched to experts for data collection. The experts are asked to assign a symbol to the relationship and co-relationship matrix respectively. In order to take the uncertainty of human thoughts into account. The symbols of the relationship matrix are transformed into triangular fuzzy numbers, using the values given in Table 2.

Step 4: The customers importance rating (CIR_{wh}) for each attribute (WHAT) is calculated. This is done by, firstly multiplying the weights (W_k) from the importance rating scale, with the frequency (F_i) of attributes given in Table 3 and then dividing each attribute with the total number of respondents (TR). The mathematical form is given in the equation below:

$$CIR_{wh} = \frac{\sum(W_k \times F_i)}{TR} \tag{3}$$

where, $i = 1,2,3\ldots$, n, it represents the i^{th} attribute, while k represents the k^{th} weight on the scale and wh represents the WHATs.

List the values of CIR_{wh} for each WHAT also known as customer requirements in the FQFD model.

Step 5: Now calculate the relative weight (RW_h) for each HOW. This is done by first, multiplying customers importance rating (CIR_{wh}) of each WHAT with the fuzzy number (FN_{wh}) assigned to it by the responded and then summing each HOW individually to get the relative weight for that particular engineering method. Eq. (4) gives the mathematical form of this:

$$RW_h = \sum_h CIR_{wh} \times FN_{wh} \tag{4}$$

where, wh represents the WHATs, while h represents HOWs of the FQFD model.

Step 6: The relative weights are in fuzzy numbers. So, de-fuzzify the relative weight of each HOW, using the centroid method (Chou and Chang, 2008). The triangular fuzzy number $FN_{wh} = (a_1, a_2, a_3)$ are de-fuzzified using the following equation:

$$Defuzzified\ RW_h = \frac{1}{3} \times (a_1 + a_2 + a_3) \tag{5}$$

Step 7: In the final step, take the defuzzified relative weights (RW_{hj}) of each HOW from all the FQFD responses collected from experts and calculate the mean (M_h) of it using Eq. (6). Then normalize the results of each HOW using Eq. (7) and finally rank them from highest value to the lowest value. The highest value being the final solution.

$$M_h = \frac{\sum_{j=1}^{r} Defuzzified\ RW_{hj}}{TE} \tag{6}$$

$$Normalization = \frac{M_h}{\sum_{h=1}^{z} M_h} \tag{7}$$

Table 2.
Fuzzy Numbers for FQFD.

Relationship Type	Weak	Moderate	Strong
Symbol	+	○	◉
Fuzzy Numbers (FN_{wh})	(0,1,2)	(1.5,2.5,3.5)	(3,4,5)

where, TE is the total number of experts that responded to the FQFD model and $(j = 1, 2, \ldots, r)$ represents the response of the j^{th} expert. Where, $(h = 1, 2, \ldots, z)$ represents the value of the HOW.

4. Data collection

Two sets of data are collected for the two techniques, that are used in this research. In both of these sets, the collection process is done through the use of different approaches. The Overall process is illustrated in Fig. 2.

4.1. First data set

In the first data set, data is collected for Multi Regression Analysis (MRA). The collection process is done in five steps. In the first step, different attributes, that customers look for in a vehicle and influences their selection process are identified through extensive study of literature and research studies. The most common and reoccurring attributes are shortlisted. In the next step, information about Pakistan's automobile market is collected from market experts and showroom owners using the mini Delphi approach. Based on experience, about fifteen experts are identified and contacted, who have at least ten years of experience and expertise in vehicle sales, customer dealings and judging customer behavior. Interviews with these experts are conducted, in this regard and information about the customer preferences, in terms of different vehicle attributes is collected. The most common and consistent attributes, from both the steps, are then selected as independent variables. A questionnaire-based on these variables is formed and distributed to a pool of sixty customers, out of which fifty-six responded back. The pool consists of car enthusiastic and multiple-car owners, who have at least 25 years of experience with different cars and are familiar with different attributes and features of the vehicles. The customers are asked to rate each attribute on a scale of zero to five in terms of their importance. Furthermore, at the end of the questionnaire, the customers are asked to state the probability (0–100), that they would prefer to buy a combustion vehicle over the electric vehicle. The preference of customers is termed as the dependent variable in our research, as it depends on the different attributes of the vehicle. The detail of attributes, importance rating scale and response summary are given in Table 3.

After the data is collected, its Cronbach alpha is calculated to check its reliability. The value comes out to be 87.51 percent. This value indicates that the data is reliable. Furthermore, it also shows that the collected data has high internal consistency. Therefore, the data can be generalized and translated as the wants of the general customer.

4.2. Second data set

In the second data set, data is collected for Fuzzy Quality Function Deployment (FQFD). The first step is the identification of different engineering solutions, that could be used to fulfill different customer requirements. In the FQFD model, engineering solutions are known as HOW and customer requirements are known as WHAT. In our research, the customer requirements are obtained from the multi-regression analysis. Based on these requirements, different engineering solutions are proposed through the extensive study of research papers. The different engineering solutions and some of the papers, from which these solutions were acquired, are mentioned in Table 4.

In the next step, a FQFD model is constructed. The model consists of different WHATs and HOWs, that are acquired in the previous steps. Based on the criteria of publications, three researchers are identified who have publications on the FQFD model and EVs in well reputed international journals. The FQFD model is sent to these three expert researchers and they are asked to assign different weights from the legends to the relationship (WHAT vs HOW) and co-relationship (HOW vs HOW) matrix. The FQFD model along with its legends are shown in Fig. 3. The responses collected from experts are then used to calculate the final

Table 3.
Importance Rating Scale, Attributes, Dependent and Independent Variables Response Summary and Experts Pool Diversity.

Importance Rating Scale	Not Preferred	Very Slightly Preferred	Slightly Preferred	Moderately Preferred	Highly Preferred	Very Highly Preferred
WEIGHTS (W_k)	0	1	2	3	4	5
ATTRIBUTES[a]	WEIGHTS FREQUENCY (F_i)					
Aesthetics	7	14	17	13	4	1
Reliability	4	14	9	13	11	5
Safety	10	21	9	11	4	1
Affordability	8	12	7	10	6	13
Mileage / Fuel Consumption	5	14	10	12	6	9
Resale Value	6	12	14	11	10	3
Durability	5	11	17	6	10	7
More Verity and Selection Option	3	17	8	10	7	11
Ease of Repair and Customization	5	7	13	12	5	14
Engine Noise	10	15	16	10	4	1

Probability[b] of choosing Combustion Vehicle over Electric Vehicles									
Percentage Range	90–100	80–89	70–79	60–69	50–59	40–49	30–39	20–29	0–19
Frequency	11	13	6	3	14	8	1	0	0

[a] Attributes: These are independent variables.
[b] Probability: This is the dependent variable.

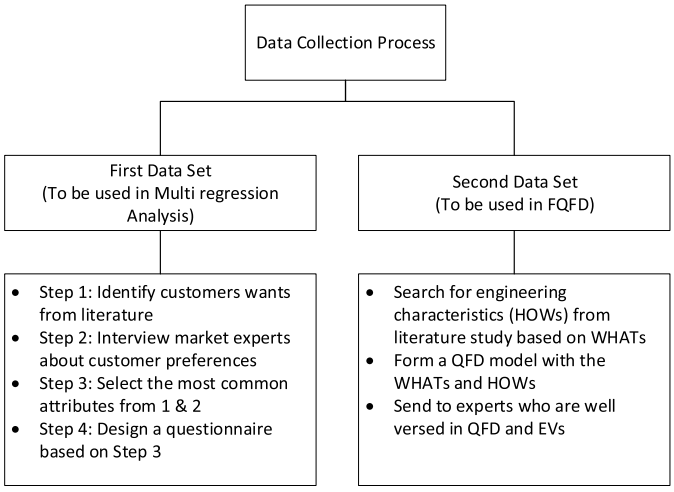

Fig. 2.. Overview of Data Collection Process (Authors own construction).

Table 4.
Engineering Solutions and Research Studies References.

HOW	Study
Powertrain Enhancing with Direct Liquid Cooled module	(Dai et al., 2016) , (Wang et al., 2014), (Hussein et al., 2015), (Li et al., 2020), (Charnesky et al., 2019)
Local Manufacturing of HEV	(Lipman and Delucchi, 2006) , (Kim, 2003) , (Breetz and Salon, 2018) , (Weldon et al., 2018) , (Baur and Todorova, 2018)
Energy management with electronic continuously variable transmission	(Chung et al., 2020) , (Zheng et al., 2020), (Jinquan et al., 2019), (Biswas and Emadi, 2019), (Xiang et al., 2017)

results, which are explained in the next section.

5. Results and discussion

Multi Regression Analysis (MRA) is used to investigate the reasons, why combustion vehicles are popular among the customers of Pakistan and why they are preferred over hybrid electric vehicles. For this reason, ten different attributes are identified as the source of appeal to the Pakistani customers, using the procedure explained in the first data set. These ten attributes are classified as independent variables. Their relationship with the probability of customers' preference of combustion vehicles is checked using MRA. The probability of customers' preference is termed as the dependent variable, as its decision rests upon the ten attributes. MRA is performed on the collected data, through excel 'Data Analysis' tool. The summary of the results is given in Table 5.

From the results, it could be seen that the collected data has a Cronbach alpha of 87.51 percent, which shows that the collected data is reliable. Moreover, there exists a 92.34 percent of co-relation between the dependent variable and the independent variables. Furthermore, the value of R^2, also called the coefficient of determination, suggests a very strong regression relationship between the dependent and independent variables. According to this value, about 85.27 percent of the variability in the customer's preference of combustion vehicle could be explained and credited to the ten attributes. The adjusted R^2 is used to compensate for the number of independent variables in the model. Even after the adjustment, the relationship value remains high, which is a positive sign. Next, the following two hypotheses are created as explained in step 5.

$$H_0 : \beta_1 = \beta_2 = \ldots = \beta_{10} = 0$$

H_a: One or more of the parameters is not equal to zero where, H_0 is the null hypothesis and H_a is the alternative hypothesis, while β_i represents the slope of the regression line for the i^{th} independent variable.

These hypotheses are created, in order to check the overall variance between the dependent variable and the independent variables. In other words, the level of significance between the set of attributes and the probability of customer preference is checked using the F test, performed at the significance level of 0.05. The results of the F test are also given in Table 5. It can be seen that the p-value of the F test is much lower than the significance level of 0.05, which means that there is variance in one or more variables. Thus, based on this result null hypothesis is rejected and the alternative hypothesis is accepted. After the F test, the *t*-test is performed to individually check the level of significance of each independent variable with the dependent variable. The hypotheses for each *t*-test are created as follows

$$H_0 : b_i = 0$$

$$H_a : b_i \neq 0$$

where, b_i represents the i^{th} independent variable. The results of t-tests, along with the decision of accepting or rejecting the null hypothesis (H_0), for all the attributes are given in Table 6.

From the results, it can be seen that the null hypothesis for the

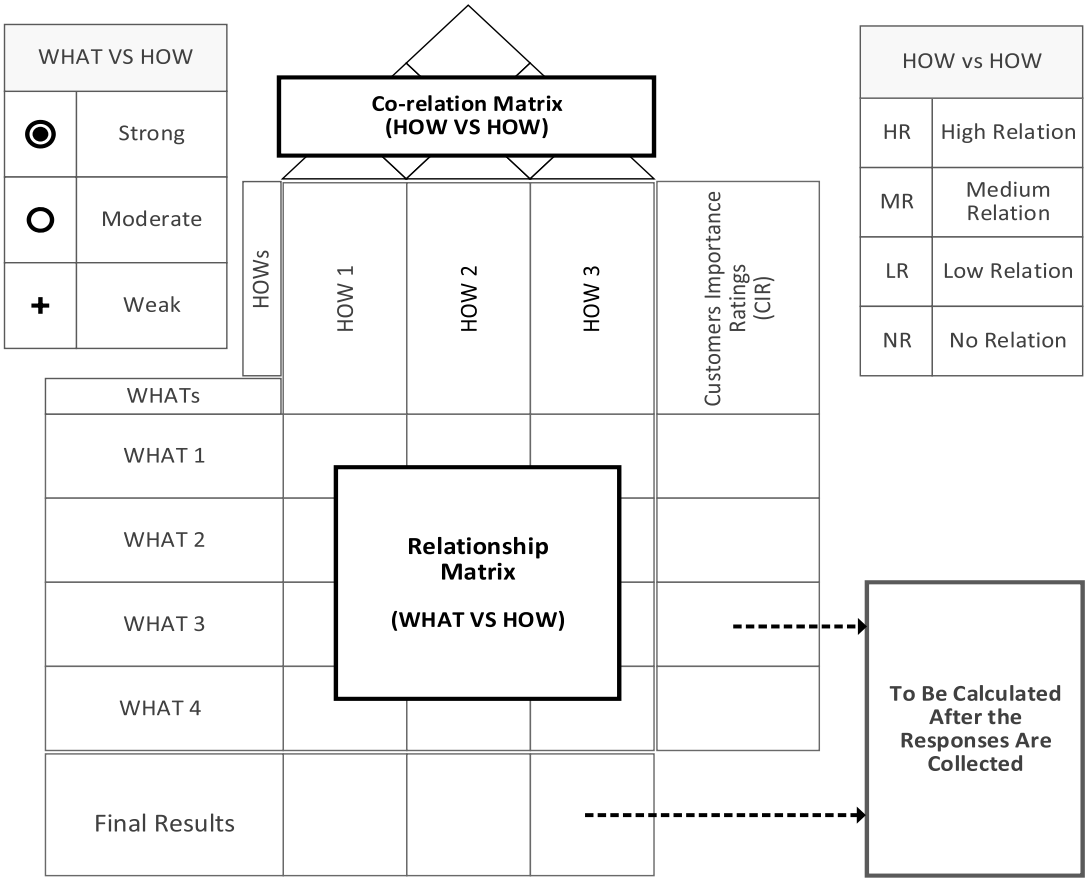

Fig. 3.. Fuzzy Quality Function Deployment (FQFD) Model (Authors own construction).

Table 5
MRA Results Summary.

Multiple Regression	R^2	Adjusted R^2	*F statistics*	*Significance Of F test / P-value*	Cronbach alpha	Total Respondents (TR)
0.9234	0.8527	0.8200	26.0561	1.6922E-15	0.8751	56

Table 6.
t-Test Results.

Attributes	t Test	P-value	Decision of H_0	Selected for FQFD	Importance Ranking
Aesthetics	0.9404	0.3520	Accept	No	5
Reliability	2.0405	0.0472	Reject	YES	4
Safety	0.3469	0.7303	Accept	No	8
Affordability	2.4345	0.0189	Reject	YES	3
Mileage / Fuel Consumption	2.9712	0.0047	Reject	YES	2
Resale Value	0.6006	0.5511	Accept	No	7
Durability	0.0314	0.9751	Accept	No	10
More Verity and Selection Option	3.4613	0.0012	Reject	YES	1
Ease of Repair and Customization	−0.6511	0.5183	Accept	No	6
Engine Noise	0.3086	0.7591	Accept	No	9

attributes, having a lower p-value than the significance level of 0.05 is rejected. This means that these variables have variance and thus have a relationship with the dependent variable. In other terms, for every change in the independent variable, there will be a change in the dependent variable. Hence, these four variables are selected for the FQFD model, as they play a significant role in the choice of vehicle or customer preference.

The four important attributes, that influence the customer's selection process, are translated into the FQFD model, as the voice of customers. These are basically the customer requirements (WHAT), that are needed to be met, in order to improve the quality and market value of a product. These four attributes are the reason, why customers opt for combustion vehicles over hybrid electric vehicles. Thus, to improve the market of hybrid electric vehicles, these same attributes should be instilled in them. For this reason, different engineering methods (HOWs) are identified using the procedure explained in the second data set and a FQFD model is constructed. The model is sent to three experts, who assign weights to the relationship and co-relationship matrix. After which, the customer importance rating (CIR_{wh}) for each WHAT is calculated by applying Eq. (3), on the data collected for MRA. The data for Eq. (3).

could be found in Table 3 and Table 5. In the next step, the relative weight (RW_h) of each HOW is calculated using Eq. (4), which is then defuzzified via Eq. (5). A complete FQFD model, along with the response collected from one of the experts and the results of Eq. (3), Eq. (4) and Eq. (5), is shown in Fig. 4.

Similar responses are collected from two more experts and their relative weights and defuzzified relative weights are calculated in the same manner. Finally, all the defuzzified relative weights from the three responses ($j = 1, 2, 3,$) are taken and the mean (M_h) of each HOW is calculated using Eq. (6), where the value of TE in the equation is equal to three. The defuzzified weights of the three responses are given in Table 7.

Afterward, the results are normalized with the help of Eq. (7), which are ranked in descending order. The HOW having the highest normalized value is the best solution, therefore it is ranked as number one. The detailed results of which are given in Table 7.

From the Table 7, it can be seen that the local manufacturing of hybrid electric vehicles, has the highest value. Therefore, it is ranked as the top solution, as it can fulfill the majority of the customer requirements and convert them into product value for EVs. It means, that the problem of low market shares of hybrid electric vehicles against combustion vehicles in the Pakistani market could be solved to great extent, by adopting this solution. The summary of the main results from both methods is given in Table 8.

Table 7.
FQFD Final Results.

HOWs j^{th} Response	Powertrain enhancing with direct liquid-cooled module	Local Manufacturing of HEV	Energy management with electronic continuous variable transmission
Defuzzified RW_{h1}	3.79	3.89	3.79
Defuzzified RW_{h2}	3.79	5.20	2.48
Defuzzified RW_{h3}	3.73	3.84	2.54
Mean	3.77	4.31	2.94
Normalized	0.34	0.39	0.27
Final Ranking	2	1	3

As evident from the results, if EVs are manufactured locally, it will automatically reduce the cost of vehicles, as the cost of production and transportation would be reduced to a great extent. Moreover, it will also remove the cost of import tax, which is normally twice the original cost of the vehicle. Local manufacturing will also increase the reliability of the EVs, as firstly they would be legally liable by the country's laws to

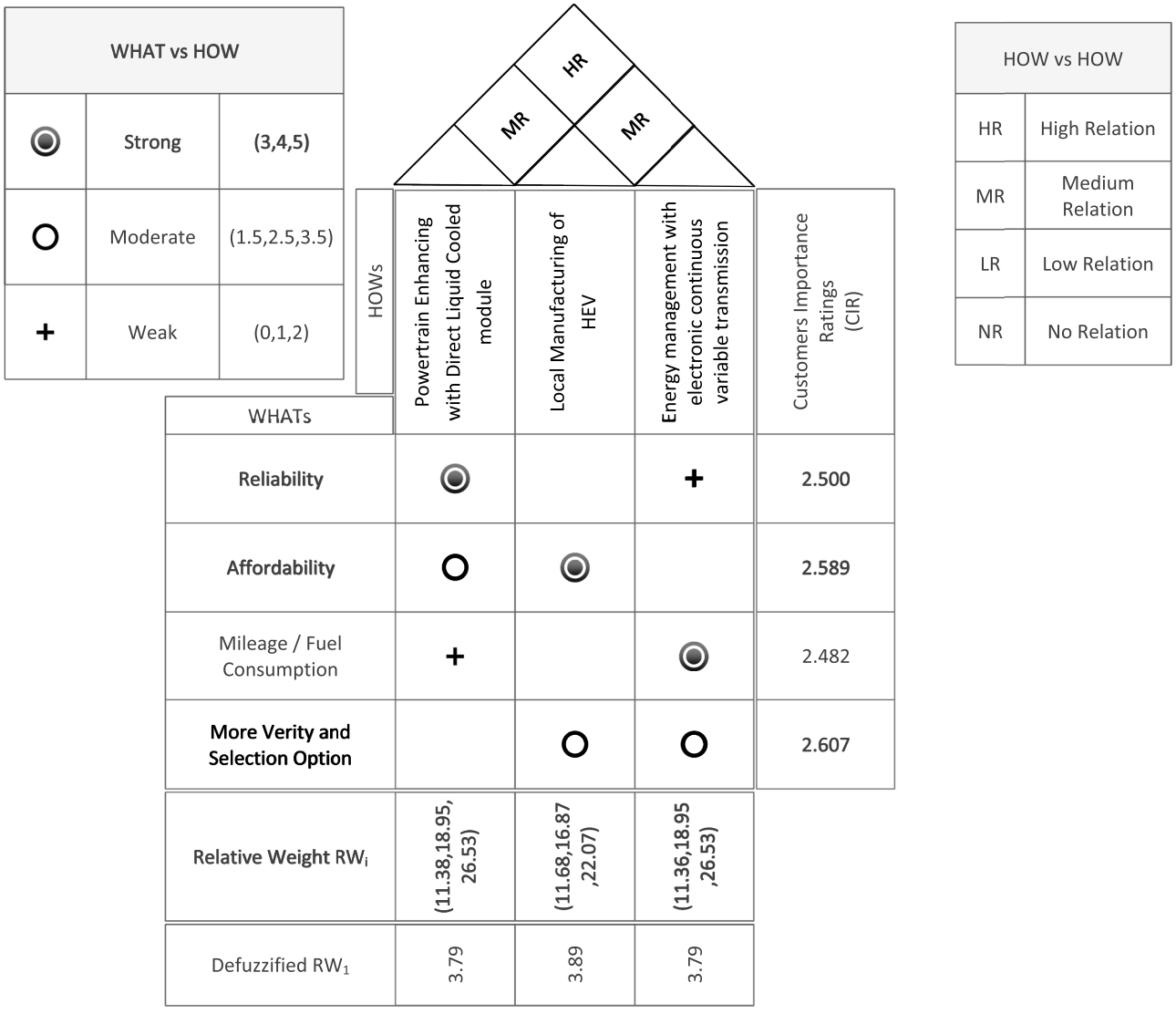

Fig. 4.. FQFD model with responses and results.

Table 8
Summary of the main finding in the study.

MRA Results: Important Attributes	FQFD Results: Best Implementation Method
Reliability	Local Manufacturing of HEV
Affordability	
Mileage / Fuel Consumption	
More Variety and Selection Option	

produce reliable vehicles. Secondly, the vehicles produced would be designed to work under the specific conditions of the specific country, which would further increase the reliability of EVs. Similarly, local manufacturing will also increase the variety and selection options, as the companies would compete with each other, so they will produce a variety of designs that could appeal to the local customers and meet their needs. However, the only attribute in which local manufacturing lags is increasing the mileage. Though this shortage could be overcome and the appeal of hybrid electric vehicles could further be boosted to Pakistani customers, by adopting the second or third solution, with the first one.

However, the choice of selecting one or a combination of these solutions depends on the cost-benefit tradeoff, associated with each of these engineering methods. To shift the balance in favor of these solutions. Currently, in Pakistan no electric vehicles are manufactured locally, which has created a huge market gap in the country for green mobility. Moreover, EVs also lack the attention and marketing in the country, due to the lack of companies which could locally manufacture and advertise EVs. It is important as this would bring EVs in the sight of customers and thus make them more acceptable to the masses. It is recommended to the policymakers of Pakistan, that a sufficient amount of incentives and tax exemptions should be offered to the manufactures. So that they are encouraged to manufacture EVs locally, rather than importing the parts from other countries and then assembling them in Pakistan. It is in line with the multiple studies conducted in Europe, which also suggests that currently, incentives play a vital role in the introduction of EVs in the countries (Hoogma et al., 2002; Biresselioglu et al., 2018). Furthermore, if EVs are manufactured locally, it would create employment opportunities and would improve the economic position of Pakistan. As Pakistan is currently importing parts and assembling them in the country, which only contributes about 2.8 percent to the country's GDP, while India locally manufactures vehicles that contribute about 14.5 percent to the GDP (Invest Pakistan, 2020; Invest India, 2020). Moreover, it would also reduce the carbon footprint of the country, as more EVs would become part of the transportation pool, which would reduce the overall carbon emission levels of the country. Owing to the fact, that hybrid electric vehicles produce 30 percent fewer emissions as compared to combustion vehicles (Jim et al., 2019). Similarly, further measures should also be put in place to encourage the use of EVs, so that in time, the next big shift from hybrid electric vehicles to full electric vehicles and then to hydrogen fuel cells could be made smoothly and effectively.

6. Conclusion

Carbon emission is an ever-increasing phenomenon, that is severely damaging the environment in the form of global warming. The prime contributor to this process is the extensive use of fossil fuels. In order to counter it and limit the reliance on fossil fuels, the world is shifting towards a greener and sustainable forms of energy resources like electric vehicles. Many developed countries around the world are adopting different types of electric vehicles as the new means of transport and similarly, developing countries are also making an effort in this direction. In these countries, the most suitable and popular type of electric vehicle is the hybrid electric vehicle, as it perfectly matches the socio-economic conditions of the country. However, despite the suitability of hybrid electric vehicles. They don't come close to competing with the combustion vehicles, in the automobile market. It poses a serious problem to the transition and adoption of electric vehicles, as the main mode of transportation in the country.

The paper aims to solve the problem by first identifying the ten attributes, that compels the customers to choose combustion vehicles over the hybrid electric vehicle. Then in the next phase, the most important of these attributes are converted into market value for hybrid electric vehicles through different engineering approaches. The techniques that are used to perform these analyses are multi regression analysis and fuzzy quality function deployment. These techniques, results in the selection of the 'local manufacturing' option, as the best engineering approach to increase the appeal of hybrid electric vehicles in the developing countries market. From an academic point of view, the results also show that the preference of the customers are influenced by the value a product has to offer. This value could be checked statically and could be instilled in other products using the hybrid technique of the paper. Likewise, company managers could also use the technique to increase the product value of their items.

Based on the final results, it is recommended to the policymakers of developing countries, that sufficient incentives and tax exclusions should be provided, in order to boost the local manufacturing of hybrid electric vehicles through shifting of the cost-benefit balance on its side. Additionally, effective future plans should be made and set into motion, so as to encourage the further reduction of carbon footprint by adopting full electric vehicles as the next big alternative to hybrid electric vehicles. Further studies could be conducted in the area of cost estimations of engineering approaches and the selection of attributes using MCDM techniques. Similarly, further studies could be conducted by selecting different sets of attributes and check their effects on the selection process. The hybrid technique itself could be applied to different sectors. The technique could be used to make the managerial decision, while also evaluating the best methods on how to implement them.

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