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Identification and Analysis of Barriers against Electric Vehicle Use

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Abstract: Electric vehicles (EVs) can be considered an alternative technology to reduce greenhouse gas emissions in the transportation sector. However, numerous barriers need to be overcome in this regard. This study is aimed at presenting the framework for the identification and analysis of barriers against the use of EVs. Then, the framework was applied to identify the challenges and rank them in order of importance against the diffusion of EVs in Nepal. Seventeen barriers were identified from previous studies, reports, policy documents, and interactions with experts. The identified barriers were classified into five categories: technical, policy, economic, infrastructure, and social. Then, a comparative survey was performed to obtain experts' opinions on the identified barriers and the analytical hierarchical process was used to analyze and rank them. The results revealed that infrastructure, policy, economic, and technical barriers pose more pressing concerns than social barriers. The lack of charging stations, relatively higher purchase price of EVs compared to internal combustion vehicles, and poor long-term planning and goal setting on the part of the government were ranked as the top three barriers against EV uptake in Nepal. This framework can be applied to replicate the study in other countries, taking their inherent relevant factors into account.

Keywords: electric vehicles; barriers; analytical hierarchical process

1. Introduction

As the name suggests, electric vehicles (EVs) run either fully or partially on electric energy supplied by the electric grid. EVs mainly comprise battery electric vehicles (BEVs) and plug-in electric vehicles (PHEVs). BEVs run on electric energy charged by plugging the vehicle into a source of electricity or an electric grid. The energy is stored in batteries. They do not consume any petroleum-based fuels. However, PHEVs use batteries to store the electrical energy from the grid and use petroleum-based fuels to power their combustion engines. EVs can be considered as an alternative to the massive use of internal combustion engine vehicles (ICEVs), which use a combustion engine, burn petroleum-based fuels, and thus emit greenhouse gases [1]. Although EVs do not produce direct emission, they can be charged from the grid. As a result, the reduction in emission depends on the primary source of electricity generation. The remarkable emission reduction of EVs can be obtained when electricity

generated from renewable energy sources (solar, wind, or hydropower) is used to charge batteries for EVs.

Worldwide, the transportation sector is gradually maturing to respond to environmental issues and energy security concerns [2]. In response to climate change, many nations are considering the adoption of EVs. However, their diffusion rates vary widely. A single policy cannot aid such diffusion; rather, a mixture of enabling policies, bearing in mind the contexts of the countries, is likely to be effective for the widespread diffusion of EVs. Such policies should consider important aspects, such as the development of EV charging infrastructure, higher purchase price, tax rebates, and subsidies for purchasing EVs [3,4].

Despite the considerable benefits of EVs, many barriers have been reported against their wider acceptance. One of the reasons for this slow uptake relates to consumer perceptions about EVs [5,6], as the popularity of EVs is significantly dependent on user acceptance. Likewise, travel behavior, government policies and support, higher pricing compared to CVs, limits regarding driving distance with a single charge, longer charging times, and economic and environmental issues are key detrimental factors affecting the uptake of EVs [7]. Adequate public charging networks, government planning, awareness raising, and enabling laws could foster the diffusion of EVs [8]. Even though EV manufacturing has progressed in technological terms, manufacturers still limit EV production due to their higher battery price and performance issues [9]. Conflicts of interest between stakeholders and poor implementation limit the development of the EV-related standards and infrastructure necessary for their diffusion [10]. The relatively higher price of an EV compared to that of a CV serves as a crucial barrier; however, environmental benefits could be the main enabler for EV uptake among consumers [11]. Addressing these barriers is crucial to the diffusion of EVs.

Previous studies have identified and reported various barriers, factors, and issues pertaining to the diffusion of EVs [12–14]. However, based on the border literature review, they did not present a framework for the identification and analysis of these barriers for the case of electric vehicle use. Moreover, no consolidated study was available that reported all of the barriers within a single framework at a specific time, and the countries' economic conditions and the availability of resources prevented all of the barriers from being addressed at one time [15]. Nor were the barriers ranked in order of their importance, which would reveal the most influential ones in decreasing order of their importance. As a result, the top-ranked barriers could be addressed first to increase the demand for EVs. A better understanding of the barriers against the use of EVs is prerequisite to overcoming the barriers in order to accelerate adaptation. The current study attempted to overcome these gaps.

The primary objective of this study was to present a framework for the identification and analysis of barriers against EVs uptake. The following methodological framework was presented to achieve this objective: identification of barriers via a thorough literature review; interaction with stakeholders; classification of the identified barriers into certain categories depending upon their nature; the use of the analytical hierarchy process (AHP), a multi-criteria decision method and a popular tool for formulating and analyzing factors or decisions, to rank the identified barriers in order of their importance.

Some of these barriers are common globally and others tend to be country specific. For instance, countries might differ in terms of their potential for EV uptake, depending on their economic situation and geographic conditions [16]. Thus, the results of a particular study may not necessarily apply to all countries. Thus, a country specific analysis is important. However, this framework can be applied to replicate the study in the context of the target country being studied.

The secondary objective of this study was to apply the presented framework to identify the various barriers against the diffusion of EVs in Nepal. This part was conducted via an extensive literature review with regard to EV deployment in Nepal. Analyses of reports and policies, as well as interactions with stakeholders, formed the foundation of this review. Seventeen specific barriers were identified and then categorized into five categories: social, technical, infrastructure, financial, and policy. The AHP was used to estimate the importance of the barriers and to rank them [17]. AHP can be used to rank alternatives by identifying criteria weights through the pairwise comparison method.

The comparison values may be sourced from surveys or the opinions of experts in the relevant field by using a fundamental nine-point scale [2,18,19]. Seventeen barriers with five categories to the use of EVs are explicitly discussed. The findings of the study, including the opinions of experts, provide several insights.

The remainder of this paper is organized as follows: Section 2 presents relevant information about Nepal; Section 3 discusses the identification and categorization of the barriers into five classes; Section 4 briefly explains the AHP process; Section 5 presents the estimation results; Section 6 concludes the paper.

2. Background

2.1. Literature Review

Traditionally, most transportation modes are highly dependent on fossil fuel consumption, which accounts for approximately 22% of carbon dioxide emissions worldwide [20]. EVs have been receiving increased attention as an alternative to lower carbon dioxide emissions, attributable to the transportation sector [7]. Thus, given the urgent need to undertake climate change mitigation efforts, nations have adopted different policies to stimulate the uptake of EVS [21]. However, such policy instruments are not consistent and differ from one country to another. Thus, the use of BEVs and PHEVs varies globally [22,23]. Nonetheless, market penetration is still very low compared to CVs due to various cost and non-cost factors [24]. The amount of emission reduction due to EVs mainly depends on the source of electricity generation, that is, the source used to charge the batteries of EVs [25–27]. Distributed or isolated energy can be used by EVs to store energy produced from renewable energy sources such as solar and wind power [28].

Previous studies reported different kinds of barriers against EV uptake in the market. Sovacool [29] pointed out that, while decision makers and technologists recognize the importance of both technical and social barriers, the latter are likely to pose bigger challenges, and thus, it would be prudent to analyze socio-technical barriers jointly to enable the adoption of EVs. Yong and Park [3] identified the factors affecting the adoption of EVs using a fuzzy set procedure. The authors concluded that economic issues and charging infrastructure should be included by governments in the consideration of financial and tax exemption policies. Prior works have highlighted many concerns, such as poor distance range, lack of recharging networks, long charging times, expensive purchase price, fuel cost, as well as brand and model availability [30,31]. Thomas [32] ranked the non-cost barriers and showed that limited awareness is the most important factor affecting EV uptake, followed by the perceptions of users, standardization limitations, lack of different models, and the absence of enabling regulations. A similar study by Browne and co-workers [33] classified non-cost barriers into six categories: commercial, administrative and institutional, public acceptance, regulatory or legal, policy failures, and infrastructure-related. Another study classified the barriers across three categories only: technological developments, fueling infrastructure availability, and elements of institutional infrastructure [34]. Improvement in technical performance was cited as a crucial factor to overcome behavioral, cultural, infrastructure-related, and economic barriers [35].

Previous research on the transportation sector has used the AHP. Tsita and Pilavachi [2] evaluated the best alternative fuels for the transport sector using AHP, while considering cost and policy criteria. Buwan and co-workers [19] studied the selection of a sustainable transportation system using AHP and considering social, economic, and environmental aspects, and they reported the social aspect as the main deciding factor. Likewise, Zang et al. [36] used the fuzzy AHP to analyze the future of fuel-cell vehicles in the Chinese market and reported that fuel availability, vehicle performance, and economic costs are the most important features with regard to vehicle selection. Ghimire and Kim [16] also applied the AHP method to rank the barriers against renewable energy development in Nepal and found economic and policy barriers to be the most important categories. While their study

is specific to EVs, some of the barriers considered by them share common ground with renewable energy development.

2.2. Nepal's Total Primary Energy Supply

Nepal does not have any fossil fuel reserves, such as coal, natural gas, and petroleum products. The country has a high potential for hydropower (approximately 83 GW) despite its current installed capacity being very low [37,38]. The share of petroleum products could be reduced if the country increased its hydroelectricity production, although this would also entail increasing its trade deficit [39]. Table 1 shows the current status of hydropower, indicating the large number of hydropower projects at different stages of construction. The data show that hydropower will be able to provide sufficient electricity for EV charging stations.

According to the National Oil Corporation Limited (NOCL), 488,675 KL and 1,588,869 KL of petrol and diesel were imported in the fiscal year 2017–2018, amounting to an increase of approximately 20% over the last year (http://noc.org.np/import-accessed date: 5 October 2018). These imports were mainly used for the transportation sector. This scenario shows that the uptake of EVs would not only provide environmental benefits but could also reduce the trade deficit for Nepal.

Table 1. Summary of hydroelectricity status [39].

Type	Number	Total Capacity (MW)
Operation (installed)	72	897
Under construction	140	3524
Applied for generation license	56	5418
Survey certificated issued	291	6802
Apply for survey certificate	812	3760
Total	1371	20,401

3. Framework for Identification and Analysis

3.1. Literature Review

The initial step in the framework development was the extensive review of previously published studies, reports, and policy documents. This step can potentially indicate the various issues, challenges, and shortcomings with reference to EVs. Country-specific transportation strategy and plans, market potential, geography, economic condition, and energy resource availability may be suitable factors in the identification of the barriers. In addition to this, case studies at local, regional, country, and global levels can be referred to, and "lessons learned" taken into account for further refinements in the categorization of these factors.

3.2. Interaction with Stakeholders

Stakeholders may include EV manufacturers, policy makers, NGOs, experts, technical experts, potential consumers and users, early adopters, and related institutions. Their opinions and perceptions should be taken into account, which are crucial not only for identifying the barriers but also for determining the lacunae in policies and measures to overcome these barriers. The identification of barriers and the implementation of policies pertaining to them are highly inter-related. Therefore, it is recommended that, preferably, both methods, literature review and interaction with stakeholders, are used for the identification of barriers against EVs use.

3.3. Categorization of Barriers

Post identification, the barriers can be classified into categories such as social, technical, economic, policy, and infrastructure, based upon their nature in the use of EVs. The categorization of these barriers can be further refined based on the considered EV technology and the country, region, or locality of the study.

3.4. Selection of Method

The multi-criteria decision method (MDCM) is well used in various decision-making processes and for ranking barriers. The weighted sum method (WSM), weighting product method (WPM), and analytical hierarchy process (AHP) are well used multi-criteria approaches. The AHP is the most popular [40], because it allows for the estimation of the inconsistency index. This index is important for ensuring the decision made is consistent and unbiased [41]. If the inconsistency index is higher than 0.10, the researcher may either ask for a re-evaluation of pairwise comparisons or exclude his/her opinion. Thus, the inconsistency checking provision may increase the persuasiveness of results.

This proposed approached has been used for the context of renewable energy [42], and we attempt a customized version of this approach for this study for the context of electric vehicle use. Likewise, the customized approach was applied to the case of Nepal, considering the AHP for the ranking of barriers.

Various researcher-conducted consumer preference surveys and applied to the discrete choice models for analyzing the use of electric vehicles [26,43,44]. However, for the purpose of ranking the barriers, this study applied the Analytical Hierarchy Process.

4. Barriers Against EV Use in Nepal

The diffusion of EVs in Nepal depends on several real and perceived barriers. As noted previously, these barriers were identified through a thorough literature review, including an analysis of relevant online content, previously published studies, and interactions with stakeholders, such as EV manufacturers, policy makers, technical experts, consumers and users, and related institutions. Specifically, an extensive literature survey was performed, searching keywords such as "electric vehicle", "barriers", "issues", "challenges", and "electrical vehicle development and Nepal". The Google, Google Scholar database, and Science Direct online searching tools were used for the literature review. Identified barriers were also refined through consultation with experts for the case of Nepal.

This approach resulted in the identification of 17 barriers relevant to EV diffusion in Nepal. Then, the barriers were classified into five categories: technical, policy, economic, infrastructure, and social. Notably, a previous study concerning renewable energy development in Nepal classified the identified barriers into six categories [16]; however, the current study does not consider the administrative nature of barriers, as EVs are new to the Nepalese market and the vehicle industry is currently run by private companies. The barriers and their respective classifications are presented in Table 2. Brief descriptions of each category of barrier appear in Sections 4.1–4.5.

Table 2. Summary of barriers to electric vehicle adoption in Nepal.

Categories of Barriers	Barriers	Literature Reference
Technical Barriers	Limited range (one-time travel distance at full charge)	[9,45,46]
	Lack of evidence on reliability and performance	[9,10,47]
	Limited battery life	[25,48,49]
	Fewer EV models	[9,10,25,50]
Social Barriers	Lack of knowledge on EVs	[8,51]
	Lack of environmental awareness regarding EVs	[25,52]
	Consumers' limited understanding of the product quality of EVs	[25,47]
Economic Barriers	Higher purchase price	[53]
	Battery replacement cost	[1,48,54,55]
	Higher electricity price for charging	[56]
	Lack of credit access for EVs	[22,35]

Table 2. *Cont.*

Categories of Barriers	Barriers	Literature Reference
Infrastructure Barriers	Lack of charging stations	[25,46,57]
	Lack of repair and maintenance workshops	[9,58]
	No domestic industry	[59]
Policy Barriers	Lack of long-term planning and goals on the government's part	[8,60]
	Absence of an annual tax exemption	[34,61,62]
	Absence of awareness raising about EVs	[8,51]

4.1. Technical Barriers

Technological advancements in the vehicle industry can play a crucial role in emission reduction and the energy efficiency of vehicles [35]. A lack of standardization, limited availability, lack of model choices, and performance issues are important factors for the diffusion of EVs [6,10]. EVs are relatively new compared to CVs, and their quality can be compromised by financial constraints at the manufacturing stage. The four technical barriers identified in this study for Nepal are explained below.

4.1.1. Limited Range (One-Time Travel Distance at Full Charge)

EV batteries must be charged for the vehicle to run and their storage capacities determine the distance that can be traveled on a single charge. One of the major user concerns for EVs is range anxiety [45,46,63]. Users who do not need to travel long distances for their daily routines are likely to show more interest in EVs [9]. Thus, limited range can be considered as an important technical barrier.

4.1.2. Lack of Evidence on Reliability and Performance

EVs are a relatively new technology compared with CVs, and potential users tend to be concerned about their technological performance, which increases their unwillingness to use EVs [9]. Lack of performance is known to affect user perceptions of BEVs [47], whereas system stability is an important detrimental factor against the increased deployment of EVs [10]. Thus, a lack of evidence regarding reliability and performance can be considered as another technical barrier.

4.1.3. Limited Battery Life

EVs run on the power provided by charged batteries. However, the typical warranty for an EV battery, improved more recently, lasts between eight and ten years. After this battery life period, battery replacement should be borne by the user. The batteries are also sensitive to overcharging, which poses a problem for EV users [48]. Limited battery life requires frequent replacements, which is a major burden on EV users [25,49].

4.1.4. Fewer EV Models

EV uptake is affected by the limited number of design models. A wider range of car models can appeal to a broader consumer segment [50,64]. Thus, limited EV model availability poses another challenge in that it narrows down choices for users [9,25]. The EV manufacturing industry is responsible for the research, development, and production of EVs. However, the production of different EV models is typically limited [10].

4.2. Social Barriers

Social factors, particularly consumer understanding of the attributes of EVs, are being recognized as significant influencing variables for users choosing EVs over CVs. The communication of related information is crucial in this regard [65]. Egbue and coworkers [1] reported that social barriers may

pose obstacles equivalent to technical factors with regard to the adoption of EVs. Consumer knowledge, experience, environmental considerations, and perceived quality of EVs affect a consumer's decision to purchase EVs. This study considers the following three social barriers against EV diffusion in Nepal.

4.2.1. Lack of Knowledge on EVs

Market failures can occur when users have incomplete information about a product. Thus, correct information provision is crucial to aid the transition towards products such as EVs [8,51]. Potential users' awareness of the benefits of an EV, financial incentives, infrastructure availability, and potential fuel-related savings are likely to be essential factors affecting the uptake of EV [66]. Notably, this barrier is limited to the provision of general information about EVs for potential users. It does not consider the users' understanding of the product quality of EVs.

4.2.2. Lack of Environmental Awareness Regarding EVs

Emission reduction is one of the key advantages of using EVs. In total, 98% of electricity is generated from hydropower in Nepal, which is emission-free. However, consumers are often uncertain about possible emission reductions due to EVs and, at times, they are environmentally unaware about the harm caused by greenhouse gas emissions due to the use of CVs [25]. Environmental awareness regarding EVs enhances the adaptation rate of EVs [67].

4.2.3. Consumers' Limited Understanding of the Product Quality of EVs

Consumers' perceptions of the quality of EVs as a product may influence their decision to purchase EVs. Uninformed or wrongly informed consumers are likely to be unwilling to purchase EVs [47]. Actual versus perceived product quality limitations, such as those related to performance and reliability, range capacity, and other technical issues, may create a perception gap among potential EV users [25]. Thus, it appears that consumers must be informed about the quality of EVs, as this particular social factor serves as a prerequisite for their acceptance. Notably, this barrier is limited to product quality concerns about EVs, as this technology is relatively new in the Nepalese market.

4.3. Economic Barriers

CVs enjoy an economic advantage, which increases consumer resistance to purchasing EVs, which are typically priced higher [53]. This relative advantage (i.e., the lower purchase price of internal combustion vehicles) is recognized as a major barrier against the uptake of EVs [11,68]. Other economic factors, such as battery replacement cost, fuel cost, and access to credit, can be considered as disadvantageous to the diffusion of EVs. Many countries now provide different kinds of financial incentives to create a competitive market for EVs. These experiences have proved that economic barriers can be addressed, to a certain extent, through such incentives [67, 68]. This study identified four economic barriers against the diffusion of EVs in Nepal.

4.3.1. Higher Purchase Price

Consumers view the higher purchase price of EVs as a major concern. Manufacturing costs are higher, hence, EVs have a higher market price than those of CVs [53]. Subsidizing EV purchase is becoming a popular tool in many countries to promote their diffusion. PHEVs tend to be even costlier due to the complexity of their dual operations [69].

4.3.2. Battery Replacement Cost

As mentioned previously, the battery life of an EV is limited to eight to ten years [48], and the consumer must bear the cost burden of its replacement. This aspect serves as a key barrier against EV uptake [54]. Previous research has also pointed out that the cost of the battery accounts for a significant proportion of an EV's total purchase price [1,70].

4.3.3. Higher Electricity Price for Charging

EVs utilize electrical energy to run compared to CVs, which use petrol or diesel. Consumers are sensitive to the cost of fuel and, thus, a higher electricity price reduces the demand for EVs [56,71,72]. The daily operation cost of an EV is mainly dependent on the electricity price for charging the EV and, thus, lower electricity prices could persuade potential EV users to purchase an EV.

4.3.4. Lack of Credit Access for EVs

Consumers are hesitant to invest in new technologies as they typically pose some measure of risk and, therefore, policy makers can play a vital role by facilitating the purchase of EVs by providing users with subsidized interest rate credit mechanisms [22]. Difficulty in obtaining credit access due to a weak or absent credit mechanism serves as another barrier against the diffusion of EVs [35].

4.4. Infrastructure Barriers

In the transportation sector, the lock-in possibility is relatively high for new technologies such as EVs, which are dependent on the available infrastructure for charging. Thus, the absence of sufficient infrastructure creates a negative network externality for the deployment of EVs [10]. Private vehicle manufacturers are of the view that the construction of the relevant infrastructure, such as charging stations and repair maintenance workshops, should be undertaken solely by the government, and vice versa [66]. This study identified three specific infrastructure-related barriers for Nepal, as explained below.

4.4.1. Lack of Charging Stations

A sufficient number of charging stations is a prerequisite for EV diffusion. The lower number of charging networks has been recognized as a limiting factor for consumers to buy EVs [1,57,67]. The public and private sectors are reluctant to invest in charging stations as the number of EV users is still insufficient and, conversely, potential EV users hesitate from purchasing EVs due to the insufficient number of charging stations [25,46].

4.4.2. Lack of Repair and Maintenance Workshops

Current EV owners are disappointed about the low number of support centers or workshops for EV repair and maintenance in comparison to those for CVs [9]. Further, EV-related repair and maintenance procedures can be complicated, and only a few trained mechanics are available to fix such issues when they arise [58].

4.4.3. No Domestic Industry

Sierzchula et al. [59] showed that EV adaptation is correlated to local vehicle production facilities, and that consumers' confidence in a product can increase, provided the industry is well-established in the country or region and they are assured that their complaints will be resolved should a problem occur with the product. Notably, Nepal does not have a domestic EV production industry at this time and, therefore, the lack of industry can be viewed as an infrastructural barrier.

4.5. Policy Barriers

In Nepal, EVs are regarded as a relatively new technology compared to CVs. However, a complete policy framework for EVs in Nepal is still under discussion among various stakeholders (policy makers, users, manufacturers, and other relevant experts). The government can implement different policies to encourage the uptake of EVs, including awareness raising, tax exemption, and long-term goal-based planning [73]. A recent study conducted by Harrison and Thiel [57] pointed out that purchase subsidies may not be able to increase EV adoption in the absence of an effective policy package and political willingness. Some policies (such as subsidies and tax exemption) might be

related to economic barriers [74], but given that EVs are new to Nepal, the absence of a comprehensive policy framework cannot be overlooked. This study identified three policy barriers against the uptake of EVs in Nepal.

4.5.1. Lack of Long-Term Planning and Goals on the Government's Part

Governments should connect the increase in EV usage at the national level to their respective sustainable development visions [60]. Long-term planning and goal development by the government could foster faster EV diffusion. Appropriate legislation, geared toward the provision of a sufficient number of charging networks, government procurement strategies, environmental awareness, subsidized purchasing, among other policies, should be included in long-term plans and goals for accelerated EV uptake [8]. Given that EV diffusion is still in its nascent stage in Nepal, the lack of long-term planning and goal setting by the government is an important policy barrier.

4.5.2. Absence of an Annual Tax Exemption Policy

Vehicle owners pay mandatory annual vehicle, road, and route permit taxes. Providing tax benefits to EV users could help the diffusion of EVs over their conventional counterparts [4,34,61,62]. Currently, Nepal does not exempt EV owners from such taxes (https://www.dotm.gov.np/en/ Tax rate for Fiscal year 2075/76).

4.5.3. Absence of Awareness Raising about EVs

According to Rogers [51], the diffusion of any new technology can be accelerated by providing potential users with the necessary information about the technology. Educational programs, advertisements, and media communications can play a crucial role in the diffusion of EVs [8]. Thus, designing and implementing awareness-raising campaigns is crucial to foster the diffusion of EVs in Nepal. Such campaigns are likely to reduce consumers' hesitation about purchasing EVs. As EVs are new to Nepal, this study considered the absence of awareness raising as a policy barrier against the diffusion of EVs in the country.

5. Method

5.1. Analytical Hierarchy Process (AHP)

The AHP is one of the popular methodologies used to estimate subjective judgment while making decisions or ranking factors and barriers. Thus, it is a decision-making model that analyzes the hierarchical structure of a research problem based on the situation at hand. In AHPs, comparative values can be sourced either from an expert survey or from actual measurements using a nine-point fundamental scale [16,41,75]. The main objective of this study was to rank the barriers identified so far against EV use in Nepal. The following steps applied:

- Step I. The goal of this research was to rank the abovementioned barriers. Accordingly, the hierarchical tree was formulated considering the 17 barriers within their respective classifications (i.e., five categories). This step decomposed the decision-making problem into a hierarchical structure [41]. Figure 1 shows the hierarchical tree for ranking the barriers against EV diffusion in Nepal.
- Step II. Pairwise comparison questionnaires were formulated with respect to the goal of the study as well as the categories of the barriers. These questionnaires were provided to experts in the field to obtain their views on a nine-point scale [75].
- Step III. Based on the experts' opinions collected through the survey in Step II, a comparison matrix was created at the category level with respect to the goal of the study, and at the barrier level with respect to each category. Next, the combined comparison matrix was created by using the geometric mean of all the respondents' opinions [76].

Step IV. At this stage, the weights for each category of barriers and specific barriers within each category were estimated using the formula $Aw = \lambda max \times w$, where A is the comparison matrix or priority matrix, w is the eigenvector (also called the priority weight), and λmax is the maximum eigenvalue [41]. The maximum eigenvalue and eigenvector can be obtained by solving the principle eigenvector. Various approximation methods exist, one of the easier methods being to normalize the rows of the combined comparison matrix [75].

Step V. The final step involved calculating the consistency of the estimation.

$$CI = (\lambda max - n)/(n - 1) \quad (1)$$

where CI is the consistency index and a zero CI value denotes perfectly consistent judgment among all respondents. λmax, is the maximum that the Eigen value can be, approximately calculated with the following equation.

$$\lambda max = average\ [(Aw)_1/w_1, (Aw)_2/w_2 \ldots \ldots\ ] \quad (2)$$

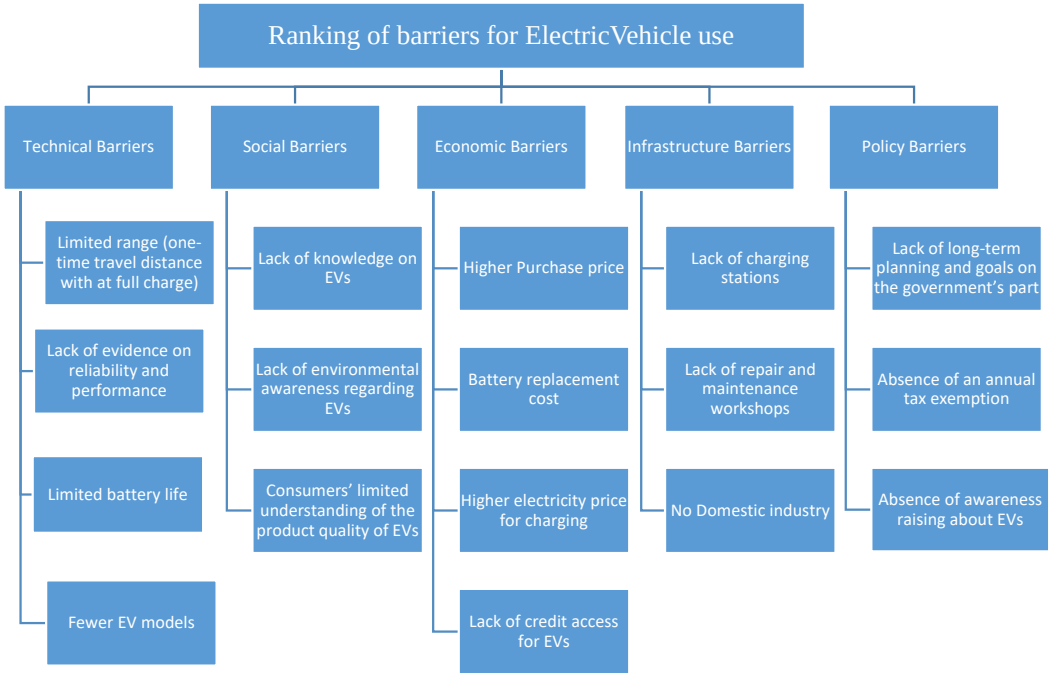

Figure 1. Hierarchical tree for ranking the barriers against EV diffusion in Nepal.

However, some inconsistencies are acceptable.

$$CR = CI/RI \quad (3)$$

where CR is the consistency ratio, and RI is the random index. The standard values of RI (for up to 10 criteria) are shown in Table 3. $CR \leq 0.1$ denotes an acceptable range.

Table 3. Random Index (RI) values [41].

Criteria Numbers	1	2	3	4	5	6	7	8	9	10
RI	0	0	0.52	0.89	1.11	1.25	1.35	1.40	1.40	1.49

Step VI. Aggregating the weight.

While we performed the research in groups of e comparative judgments can be combined by applying the geometric mean to the views for the formation of the comparison judgment Matrix [76].

5.2. Survey and Data

This study considered experts working in the fields of energy, environment, and transport in the government sector. Experts in vehicle-related institutions as well as people using a vehicle or intending to use one were also considered. In general, people do not have proper information about the benefits and advantages of EVs, such as lower fuel cost, less maintenance, and less emissions. Thus, we expected experts from the energy and environment sectors to be aware of the importance of EVs to a better extent than a layperson. The respondents were provided with detailed information about the barriers against the diffusion of EVs in Nepal and were requested to compare all of the barriers in terms of their perceived importance on the aforementioned nine-point scale. A systematic guide on the AHP and details of the survey procedures are provided in various studies [76–80]. We requested more than 60 experts to participate in the survey. We received 53 complete and consistent datasets for the estimation. Stakeholders compared the listed barriers on survey questionnaires. This survey was performed in December, 2018.

For better transparency of the proposed model, and to ease understand of the research, the consolidated overall research flow chart is presented in Figure 2.

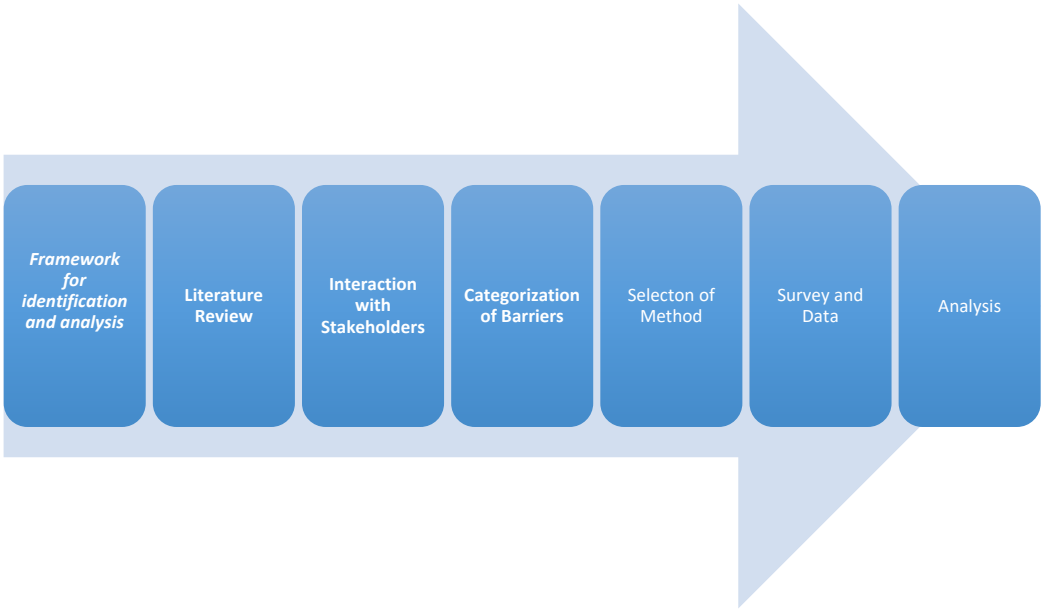

Figure 2. Consolidated flow chart of study.

6. Results and Discussion

6.1. Ranking Barrier Categories

The results of the AHP estimation are shown in Table 4. Among the five categories of barriers, these results, derived from experts' opinions, rank infrastructure barriers (24.60%) as the most crucial category of barriers against EV diffusion in Nepal, followed by policy barriers (24.07%), economic barriers (23.74%), technical barriers (19.38%), and social barriers (8.21%). Notably, the infrastructure, policy, and economic barriers are not significantly different in terms of weight, which means that all three categories pose significant challenges. The results show that, while social barriers pose a challenge, they affect the uptake of EVs to the lowest extent compared to the other four barrier categories.

Initially we checked the consistency at each individual level. We did not consider response, which was inconsistent for this research; however, we have presented the consistency index for the aggregated response matrix only.

Table 4. Categories of barriers ranking for electric vehicle use.

Barrier Categories	Priority Weight	Priority Weight (%)	Rank
Technical Barriers	0.194	19.38	**4**
Policy Barriers	0.241	24.07	**2**
Economic Barriers	0.237	23.74	**3**
Infrastructure Barriers	0.246	24.60	**1**
Social Barriers	0.082	8.21	**5**

Consistency Ratio (CR) = 0.00247.

6.2. Ranking Within Categories

Next, the ranks of the barriers within each category, in terms of their percentage weights, were estimated. Table 5 shows that limited range (namely, one-time travel distance with a fully charged battery) is ranked first (31.34%), which implies that the greatest obstacle to using EVs in Nepal is technical in nature. Limited range was followed by limited battery life (28.16%), lack of evidence regarding reliability and performance (23.66%), and absence of different models (15.90%).

Table 5. Technical barriers rankings.

Technical Barriers	Priority Weight	Priority Weight (%)	Rank
Limited range	0.313	31.34	**1**
Lack of evidence on reliability and performance	0.237	23.66	**3**
Limited battery life	0.282	28.16	**2**
Fewer EV models	0.169	16.91	**4**

Consistency Ratio (CR) = 0.03.

Table 6 indicates that consumer understanding regarding quality (42.42%) is the most influential social barrier, followed by lack of knowledge about EVs (31.14%), and lack of environmental awareness about using EVs (27.52%).

Table 6. Social barriers rankings.

Social Barriers	Priority Weight	Priority Weight (%)	Rank
Lack of knowledge on EVs	0.311	31.14	**2**
Lack of environmental awareness regarding EVs	0.275	27.52	**3**
Consumers' limited understanding of the product quality of EVs	0.414	41.42	**1**

Consistency Ratio (CR) = 0.02.

Table 7 indicates that higher purchase price (54.83%) is ranked as the most crucial economic barrier against EV uptake in Nepal, followed by the battery replacement cost (24.01%), lack of credit access (12.14%), and higher electricity price for charging (9.02%).

Table 7. Economical barriers rankings.

Economical Barriers	Priority Weight	Priority Weight (%)	Rank
Higher purchase price	0.548	54.83	**1**
Battery replacement cost	0.240	24.01	**2**
Higher electricity price for charging	0.090	9.02	**4**
Lack of credit access for EVs	0.121	12.14	**3**

Consistency Ratio (CR) = 0.04.

Likewise, with regard to the infrastructure barriers, Table 8 shows that a lack of charging stations (55.89%) is ranked as the most important obstacle against EV use in Nepal, followed by a lack of repair and maintenance workshops (27.80%) and the absence of a domestic industry (16.28%).

Table 8. Infrastructure barriers rankings.

Infrastructure Barriers	Priority Weight	Priority Weight (%)	Rank
Lack of charging stations	0.559	55.89	**1**
Lack of repair and maintenance workshops	0.278	27.80	**2**
No domestic industry	0.163	16.28	**3**

Consistency Ratio (CR) = 0.01.

As per Table 9, within the policy barriers category, a lack of long-term planning and goal setting by the government (50.93%) is estimated to be the most important barrier, followed by the absence of a tax exemption policy (28.14%) and a lack of awareness raising about EVs (20.87%).

Table 9. Policy barriers rankings.

Policy Barriers	Priority Weight	Priority Weight (%)	Rank
Lack of long-term planning and goals	0.509	50.93	**1**
Absence of an annual tax exemption	0.281	28.14	**2**
Absence of awareness raising about EVs	0.209	20.87	**3**

Consistency Ratio (CR) = 0.001.

6.3. Overall Ranking

The global weight of the barriers was calculated by multiplying the priority weight of each category with the relevant priority weight of the barrier within that category. The global weight of the barriers is presented in Figure 3, in terms of the degree to which each barrier hinders EV diffusion in Nepal. The lack of charging stations (13.6%), higher purchase price (12.6%), and absence of long-term planning and goal setting by the government (12.1%) were ranked as the top three barriers, followed by the lack of repair and maintenance workshops (6.9%), absence of a tax exemption policy (6.7%), limited range (6.1%), limited battery life (5.7%), battery replacement cost (5.5%), and lack of evidence with regard to reliability and performance (5.2%). The results shows that the absence of awareness raising (5.0%), lack of domestic industry (4.1%), the consumer's limited understanding of the product quality (3.5%), and there being fewer EV models are moderate level barriers. The overall ranking results indicate that higher electricity price (2.1%) is the least important barrier, followed by the lack of environmental awareness about EVs (2.3%), the lack of knowledge about EVs (2.6%), and the absence of credit access to purchase EVs (2.8%).

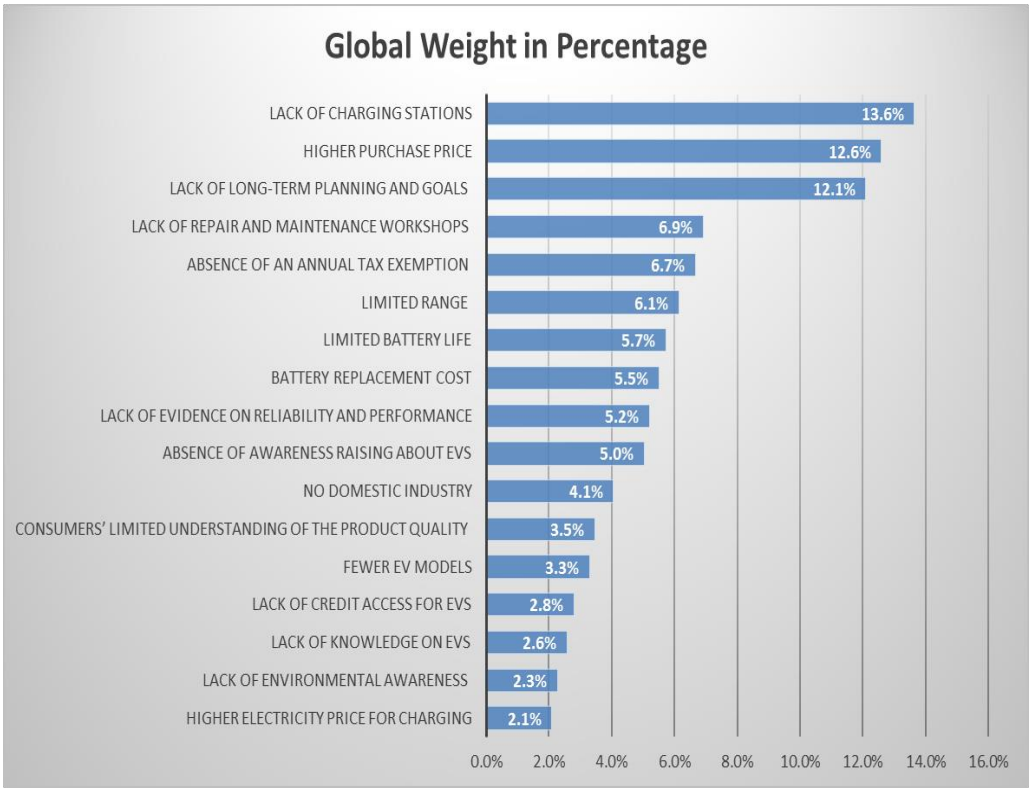

Figure 3. Overall ranking of barriers (global weight in percentage).

6.4. Discussion

First, this study attempted to present the approach for the study of barriers against EVS use. Secondly, the presented framework was applied in the context of Nepal. The abovementioned results are likely to have significant implications for decision makers in the government, EV manufacturers, and other interested stakeholders who want to understand the barriers against EV use in Nepal, as well as their relative importance. Our results show that the infrastructure, policy, economic, and technical barrier categories present considerable challenges in this regard, whereas social barriers are less important in comparison. A similar study conducted for Kasongan city in South Korea showed poor social acceptance of EVs as the main barrier [19], but our work suggests otherwise. This difference can be attributed to the fact that such studies are always location- and case-specific. Our results are similar to those of another study conducted for fuel-cell vehicles, wherein infrastructure, technical, and economic challenges were identified as the most important dimensions affecting consumer attitudes towards fuel-cell vehicles [36]. Our results also indicate that the top three ranked categories of barriers had similar weights, which shows that, while the origins of the barriers are diverse, it is crucial to address them simultaneously to ensure successful EV diffusion in Nepal. Thus, adopting an integrated approach, rather than focusing on a specific barrier, is a must.

As EVs are a relatively new technology in comparison with CVs, consumers are unlikely to invest in EVs unless the supporting infrastructure exists. Thus, policy makers and EV manufacturers should work together to facilitate the creation and maintenance of the relevant infrastructure [66]. Among the four barriers listed in the infrastructure category, the lack of charging stations was ranked the highest, followed by the lack of repair and maintenance workshops, and the absence of a domestic industry. The results indicate the relatively high importance of charging stations in comparison with the other two barriers. Our results support previous findings that showed the existence of an indirect network effect pertaining to charging and service stations. Thus, government intervention and partnerships with the private sector toward infrastructure creation are crucial to achieve any targets for EV diffusion [81,82].

Policy barriers were ranked as the second most important barrier category. As EVs are new to Nepal, the government is yet to devise EV-specific policies for their promotion. Different policy instruments would likely be needed to promote EV usage, based on specific government plans and goals. Such policies would include tax exemption and awareness creation. Our results show that long-term planning and goal setting by the government is the most important policy-related factor affecting EV use. Policies on tax exemption and awareness creation will play a supporting role for the deployment of EVs in Nepal. For instance, awareness raising will provide important information to potential consumers regarding the incentives of purchasing and using EVs, the infrastructure needed for EVs, their quality, and their role in emissions reduction [8]. These results are in agreement with the findings of Yong and Park, who also suggested that a policy mix is crucial for EV diffusion [3].

The economic barriers against EV diffusion in Nepal also deserve attention. The experts' opinions revealed that the relatively high purchase price of EVs was ranked as the highest in this category, followed by battery replacement cost, lack of credit access, and higher electricity price. Previous studies also identified the higher purchase price as a crucial factor and suggested that purchase subsidies could provide a competitive edge to EVs over CVs [3,4,10]. In addition, battery replacement cost and credit access mechanisms need to be considered. Electricity price for recharging the batteries of EVs was shown to be the lowest ranked barrier. This result may be attributed to the low price of electricity compared to gasoline in Nepal, where 98% of electricity is generated by hydropower, which is a relatively cheap source of electricity.

Technical barriers were ranked as the fourth most important barrier category in this study. The findings show that experts continue to have doubts about the technical performance of EVs. Within the technical barriers category, the limited range problem was ranked as the most crucial barrier, whereas the lack of different models was ranked the lowest. The number of charging stations can reduce the limited range problem [82]. The results also revealed that limited battery life and lack of evidence regarding EV reliability and performance were the second and third barriers in the technical category, respectively, with their weights being similar to that of the limited range problem. Thus, the results indicate that these technical issues need to be resolved in order to encourage the uptake of EVs in Nepal.

Social barriers were considered to be the least important, as the experts did not perceive these features to be as vital as the other challenges. Within the social barrier category, consumer understanding of quality was ranked as the most important, followed by the lack of knowledge regarding EVs and the lack of environmental awareness. Thus, the results reveal that the average consumer is likely to be uninformed about the advantages of using EVs, as well as their quality and actual performance. Thus, it is vital that information about EVs be disseminated to heighten consumer understanding and awareness.

The global weights presented in Figure 3 point to the lack of charging stations, higher purchase price, the lack of long-term planning and goal setting by the government, the absence of repair and maintenance workshops, and the absence of a tax exemption policy as the top five ranked barriers against diffusion of EVs in Nepal. Moreover, the higher electricity price, lack of environmental awareness with regard to EVs, poor knowledge about EVs, and lack of credit access were ranked as less important barriers against the deployment of EVs in Nepal. It is evident that the top-ranked barriers should be addressed first.

7. Conclusions and Policy Implications

This study presented a framework for the identification and analysis of barriers against EV use. Reported literature reviews, including previous research, reports, and policies and plans, were studied for the identification of barriers, followed by interaction with stakeholders. EV manufacturers, policy makers, NGOs, technical experts, potential consumers and users, early adopters, and related institutions were considered as potential stakeholders. The identified barriers were further classified into certain number of categories, depending upon their nature. Further, the proposed framework was applied for

the identification and analysis of barriers against EV use in Nepal using the AHP. The presented and employed approach could be useful for future researchers who may use benchmarking to contribute further to EV barrier studies.

The diffusion of EVs in Nepal is important, given that concerted EV uptake will serve as an effective climate change mitigation measure. Moreover, it can help to reduce the country's trade deficit with regard to petroleum products. While Nepal does not have fossil fuel reserves, unlike other countries, its hydropower potential is very high. Electricity produced using hydropower will help provide the needed electricity for charging EV batteries.

We identified 17 barriers against EV uptake in Nepal from an extensive review of previous research, reports, and interactions with experts. Then, the barriers were classified into five categories: technical, policy, economic, infrastructure, and social. Importantly, this study presents the first attempt, in the context of EV usage in Nepal, at ranking such barriers using the AHP and experts' opinions on their relative importance. Insufficient infrastructure was the highest-ranked barrier category, followed by policy, economic, technical, and social barriers. The global weight analysis pointed to the lack of charging stations, higher purchase price, lack of long-term planning and goal setting by the government, absence of repair and maintenance workshops, and the absence of a tax exemption policy as the top five ranked barriers against the diffusion of EVs in Nepal.

The findings of this study will provide guidance to decision makers, EV manufacturers, and other stakeholders towards promoting EV diffusion in the country. Moreover, the study demonstrated the successful use of the AHP towards such an analysis. Given that some barriers are common globally, whereas others tend to be country-specific, the results of one study will likely not be applicable to another country. However, the proposed framework can be replicated in other countries to identify and rank the barriers. Thus, a customized analysis is important for a region or country.

It is difficult to say which barriers are country-specific and which are common globally. However, for example, a lack of long-term plans and goals, and a higher purchase price could be important barriers to Nepal. At the same time, these two barriers might not be crucial to those countries who already have long-term plans and goals with subsidy or tax exemption policies for EVs. The results of this study might not be relevant to other countries, as this ranking was particularly for the context of Nepal. However, the framework can be applied to other countries to identify the barriers.

The higher purchase price of EVs create doubts about their economic benefit in long run. The upfront cost of EVs is still higher; however, the operating costs are much lower (https://kathmandupost.com/climate-environment/2019/10/26/electric-vehicles-are-the-future-of-mobility-but-is-nepal-ready). We believe that researchers should focus on economic analysis of EV use compared with ICEVs. We believe that the operating costs of EVs in Nepal would considerably lower compared with ICEVs.

Moreover, it is possible that other barriers against EV promotion may exist or arise in the future. Thus, frequent and continued literature reviews and interactions with users, manufacturers, experts, and policy makers are necessary to identify such issues in a proactive manner.

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