Evaluating the Effect of Policies, Vehicle Attributes and Charging Infrastructure on Electric Vehicles Diffusion in Kathmandu Valley of Nepal

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Abstract

This paper outlines the electric vehicle development trajectory and examines the principal factors that can uplift the growth of electric vehicles and contribute to future market share of electric vehicle based on public expectations from government in terms of vehicle infrastructure and attributes, situation and policies. Public's expectations, their willingness and attraction towards electric vehicles has been understood based on various questionnaire posed to them in the online public response survey. Current status of electric vehicles has been obtained and policy study in promotion of electric vehicles in India, China and Bhutan has been studied to incorporate the major factor contributing to influence the promotion of electric vehicles in Nepalese vehicle market. In this paper, the System Dynamics Model has been selected for evaluating electric vehicle growth based on vehicle attributes, government policies charging infrastructure. Public and electric vehicle promoter acceptability survey has been performed and the importance and attractiveness of electric vehicles under key factors has been determined. The number of future electric vehicles in market of Kathmandu has been forecasted to reach nearly 10, 00,000 within three years and remains constant. During the course of this research, a unique electric vehicle diffusion model, which is an adaptation of Struben and Sterman model, has been developed. This model is relevant to Nepalese electric vehicle market and social structure and hence is expected to work better than the former one, at least in context of Nepal.

Keywords

System Dynamics Method, Electric Vehicles Forecasting, Electric Vehicles, VENSIM-PLE

1. Introduction

Electric vehicle development in the Kathmandu Valley has begun in 1993 as a response to the urgency of a severe air pollution situation. The dynamics of government intervention, non-governmental organization advocacy, international donor support, and private sector involvement all shaped EV implementation in various ways. Its success led other South and East Asian cities to view it as a model for implementing EVs to alleviate air pollution. Yet despite a promising beginning and intensive proliferation, the EV industry was failing only six years after its inception and till now, the industry has no any significant growth in the country. What went wrong with a development that seemed to have all the makings of success at the beginning? What is the current status? What will be future growth of Electric Vehicles based on different policies and EV features?

In fight against air pollution and greenhouse gas emissions, the electrification of the transport sector is an important goal because widespread electrification would greatly improve the quality of the air we breathe. And in fact, switching to electric vehicles has also been a core target of the Ministry of Forests and Environment since 2015, when Nepal’s Nationally Determined Contribution was established [1]. Also, emissions from the transport sector constitutes of 69% of total emissions per year in Kathmandu valley [2, 3].

Nepal has a comparative advantage in terms of production of its own hydroelectricity, a local energy resource, with a huge potential to replace imported fossil fuel in upcoming days resulting the energy
security of country. Also, EVs are the cleaner, greener, and quieter alternative money saving and cheaper in the long run and are dependent on domestic energy sources of Nepal. Maharjan [4] outlined the EV development and examines the major factors that hurdled the progress during 2000 AD, but role of polices and vehicle attributes in realization of growth of electric vehicles were not focus of that study. Shakya [5] studied about low carbon development strategies i.e. role of transport sector electrification and carbon tax in Nepal. This study has no relevance in this research as it was made to examine the mid and long term effects of a sectoral low carbon strategy by developing transport electrification scenarios. Still, there are very few research conducted which examines the status of EVs in capital city and estimate the growth by analyzing barriers in different policy scenario. In this context, a study on EV development might shed new light on the dynamics of EV adoption and the barriers it faces in its implementation which ultimately provides policy recommendations for promotion EVs in Kathmandu Valley with realization of potential benefits.

This study is focused on understanding the status of electric vehicle development and examining the role of government policies, vehicle technical features and the development of infrastructure in the private EV promotion in Kathmandu Valley, rather than the exact prediction of the future EV population. Kathmandu is the capital city of Nepal and it’s population is projected to double by 2030 [6] and considered as largest among cities of Nepal according to population. About 46.2% of the total vehicles registered in the country are registered in the Bagmati zone [7]. The annual average growth rate of the total registered vehicles in the Valley from 1990-2011 is 14.32% [8]. Introduction of policies favorable to battery powered vehicles could at least replace this incremental rate by EVs. Reduction in purchase and operation costs, charging duration can create a huge acceptability of electric vehicles in Kathmandu Valley. Similarly, construction of charging infrastructure around the valley could provide solution to worries of the general public while purchasing an EV. The study has been undertaken to examine the influence of key factors on growth rate of electric vehicles based on public and promoter aspects and to promote EVs in Nepal in different scenarios.

This research is supported by a customer preference survey which is an inclusive survey, where despite its small sample size, has incorporated people’s thoughts from different backgrounds. The word of mouth of EV drivers and EV non-drivers has been taken separately to better analyze the customer preference and situation. Special attention has been paid for this inclusiveness of the survey.

The second section of this paper describes in brief the problem formulation and the general methodology followed in the paper. On the next section, the modeling and mathematical part of the research is included, where details of modified Struben and Sterman model used here, and their mathematical bases are also included. The fourth section of this paper is dedicated towards the survey results and its sample distribution, which, is far more important aspect of this research than meets the eye. Finally, the next two sections describes the results obtained and conclusions of this study respectively.

2. Problem Formulation and Methodology

Figure 1: Flowchart Showing the Paper General Methodology

The diffusion model of the Nepalese market based on the model of Struben and Sterman [9] was built with
some modification to match research goal. Struben and Sterman emphasize a broad boundary of AFV transition, “including attributes, driver experience, word of mouth, marketing, learning through R&D and experience, innovation spillovers, and infrastructure” [9]. However, the research did not consider the effect of policies, which is a key factor in Nepalese EV promotion. This research has focused on key factor, including policies, charging infrastructure and vehicle attributes. Moreover, the model has considered those factors from consumer preference view. Secondary data has been obtained from governmental and non-governmental organizations. Primary data has been obtained from field visit/questionnaire survey to estimate different parameters of our modified Struben and Sterman Model.

In several works, the Struben and Stermen EV Diffusion model has been used. For example, in a study in context of Shenzhen [10], the authors used it to investigate the influence of infrastructure development plans, duration of policies, and phase out strategy of policies. Similarly, System Dynamics Method has been used by Turan and Yücel [11] to evaluate the plausible diffusion patterns of electric vehicles for Istanbul and extent of the diffusion rate in Istanbul after three decades.

The general methodology followed during this method is shown in Figure 1. Development of different models, calculation of different states and their tabulation for a period of 10 years of time in 120 iteration, where one iteration is equivalent to 1 month, is implemented in this paper. In each of the iterations, the model is run completely, updating the values of the variables and recording/tabulating the results as per our requirement.

The general methodology, as seen in Figure 1, includes the development of dynamic models for emotional acceptance of EV diffusion and rational choice, as recommended by [12, 13].

In the next figure, Figure 2, the specific methodology explaining the method of System Dynamics implemented in this paper is shown. Here, the interaction between different aspects, viz. government policy, public emotional aspect, their response, etc are elaborated.

The methodology of the paper, giving special emphasis to the System Dynamics model is provided in the second flowchart, presented here in Figure 2. It includes all the works done in the research, including the literature review, review of government policies in Nepal, China, Bhutan and India, brief structure of policy scenario development, survey structure, and the incorporation of survey results.

The survey questionnaire used are generally relating to the public’s response to easy taxation, purchase subsidy, environmental impact of EVs, ease in operation and maintenance of EVs, their willingness to recommend EV to someone else based on these qualities of EV, and in addition to these, the survey collects their expectations from government side for emphasis on growth of EVs.

![Flowchart Showing the Paper Specific Methodology](image)

3. Model Development

The system dynamics model developed in VENSIM-PLE for this study consists of two major parts. The first one, concerning to general public’s response to government policy, their understanding of EVs and their general necessity, is termed as Emotional Acceptance part. This part takes the public’s response obtained from our survey and using appropriate mathematical procedures, calculates the public’s overall willingness to consider buying an
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Figure 3: Emotional Acceptance Models

Figure 4: Government Policy and Allied Models

Figure 5: VENSIM Complete Model
electric vehicles. A snap of the model developed in VENSIM-PLE is provided in the following figure, Figure 3.

In order to incorporate the government policy, EV infrastructure and vehicles attributes, the model regarding government policy and related aspects was developed and is shown in Figure 4. This part of the model includes the response of people regarding how important a factor is for them to consider buying an EV. The factor includes the detail of the government policy, charging infrastructure and EV attributes. These are explained in detail in the following table, Table 1.

**Table 1: Factors Affecting Rational Choice of EV**

<table>
<thead>
<tr>
<th>Category</th>
<th>Factors</th>
</tr>
</thead>
<tbody>
<tr>
<td>Government Policy</td>
<td>Purchase Subsidy, Taxation</td>
</tr>
<tr>
<td>Vehicle Attributes</td>
<td>Purchase Cost, Operation Cost, Charging duration, Driving range</td>
</tr>
<tr>
<td>Charging Infrastructure</td>
<td>Number of Charging Stations, Charging place</td>
</tr>
</tbody>
</table>

### 3.1 Mathematical Models of Different Blocks

While calculating the growth of EVs, the response of public to the government policy obtained by the survey needs to be incorporated into the mathematical models developed. The mathematics behind this incorporation is explained in this section.

The response of EV drivers should contribute more to the results because one who has actually used an EV knows better about its aspects. The survey results of EV drivers is converted to what is known as Word of Mouth, which is calculated as shown in Equation 1 [9, 10].

\[
WOM_D = Q_1 W_1 \left(\frac{V}{N}\right) \quad (1)
\]

Similarly, the response of non-EV drivers are quantified using the following formula, Equation 2.

\[
WOM_O = Q_2 W_2 (1 - \frac{V}{N}) \quad (2)
\]

Where,
- \(q_1\) and \(q_2\) are contact effectiveness
- \(W_1\) and \(W_2\) are willingness to consider calculated from survey responses
- \(V\) = Total number of vehicles (EV + CV)
- \(N\) = Number of EVs

Another important factor that decides the total social exposure and provides a measure of effect of marketing of EVs is Marketing Effectiveness Factor \(\lambda\). The complete measure of total social exposure is given as the sum of these three factors, as shown in Equation 3.

\[
\tau = \lambda + WOM_D + WOM_O \quad (3)
\]

During the EV consideration stage, the willingness to consider or consideration rate varies as shown in Equation 4, the integration of which, gives us the total willingness to consider, \(W\) [9, 10].

\[
\frac{dW}{dt} = \tau (1-W) - \phi W \quad (4)
\]

Here, \(\phi\) is the decay rate of \(W\).

The differential equation in 4, after solving it, could also be written as follows.

\[
W = \frac{\frac{\tau}{(1+(\tau-\phi)t)}}{(1+(\tau-\phi)t)} \quad (5)
\]

In order to get a modified Struben and Stermen model, Equation 5 has been used instead of Equation 4. The reason behind using the modified model instead of the original model is that the modified model provides much more relevance to the current condition of vehicles and transportation in Nepal. The discards of any vehicles is very low, the EV drivers’ willingness to consider is not always a full hundred percent, and the interrelation between government policy and EV attributes is rarely seen, due to which the modified model portrays the condition of Nepal’s electricity market more appropriately than the original model.

The calculation of the decay rate \(\phi\) is given as, Equation 6 [9].

\[
\phi = \frac{1}{1 + exp\left(-2\left(1 - \frac{1}{\tau^*}\right)\right)} \quad (6)
\]

Where,
- \(\tau^*\) = reference social exposure when \(WTC\) decays at the rate of 50%.

The probability of purchase is given as,

\[
P = \beta_p * a_p + \beta_c * a_c + \beta_v * a_v \quad (7)
\]

\(\frac{V}{N}\) = Share of EVs in Market  
\(1 - \frac{V}{N}\) = Share of CVs in Market
Where, $\beta_p$ and $a_p$ are government policy importance and attractiveness factors respectively $\beta_v$ and $a_v$ are vehicle attributes importance and attractiveness factors respectively $\beta_c$ and $a_c$ are charging infrastructure importance and attractiveness factors respectively

The constituents of these critical factors are shown in Table 1.

### 4. Survey Sample Description

During the survey of general public in Kathmandu, the people who contributed to the survey were of different social and educational background. Special attention has been paid to make the inclusive and representative of whole population of Kathmandu. The survey sample description is presented in the table below, Table 2.

<table>
<thead>
<tr>
<th>Index</th>
<th>Variable</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gender</td>
<td>Male</td>
<td>88.3%</td>
</tr>
<tr>
<td></td>
<td>Female</td>
<td>11.7%</td>
</tr>
<tr>
<td>Age (years)</td>
<td>18-22</td>
<td>20.2%</td>
</tr>
<tr>
<td></td>
<td>22-35</td>
<td>73.3%</td>
</tr>
<tr>
<td></td>
<td>35+</td>
<td>6.5%</td>
</tr>
<tr>
<td>Occupation</td>
<td>Staff</td>
<td>22.7%</td>
</tr>
<tr>
<td></td>
<td>Advance Management</td>
<td>5.3%</td>
</tr>
<tr>
<td></td>
<td>Private Firm Owner/ Business</td>
<td>13%</td>
</tr>
<tr>
<td></td>
<td>University Student/ Student</td>
<td>43.7%</td>
</tr>
<tr>
<td></td>
<td>R&amp;D Engineer</td>
<td>15.4%</td>
</tr>
<tr>
<td>Driving Experience</td>
<td>Less than 3 years</td>
<td>36%</td>
</tr>
<tr>
<td></td>
<td>3-5 years</td>
<td>15.4%</td>
</tr>
<tr>
<td></td>
<td>5-8 years</td>
<td>11.3%</td>
</tr>
<tr>
<td></td>
<td>More than 8 years</td>
<td>18.2%</td>
</tr>
<tr>
<td></td>
<td>Not Applicable</td>
<td>18.2%</td>
</tr>
<tr>
<td>Willingness to buy EV in 2 years</td>
<td>Already have an EV</td>
<td>3.6%</td>
</tr>
<tr>
<td></td>
<td>Considering to buy an EV</td>
<td>40.5%</td>
</tr>
<tr>
<td></td>
<td>Not Sure</td>
<td>47%</td>
</tr>
<tr>
<td></td>
<td>Not Considering to buy an EV</td>
<td>8.9%</td>
</tr>
</tbody>
</table>

Table 2: Sample Description

Similarly, the change in total social exposure and decay rate, and their effect in willingness to consider is shown in the following figure, Figure 7.

It could be observed that if the current policy and infrastructure regarding EVs is up to customer’s expectations, the number of EVs in Kathmandu will grow from 3479 to 950,000 in ten years. But in order to obtain the growth, the government policies, EV attributes, and infrastructures should be as per the customer expectations, as stated above.

### 5. Results and Discussion

Based on the model developed in VENSIM, the graphs showing change of different variables such as probability of purchase, high potential customers, and number of EVs were obtained. As seen in the model in Figure 5, it is seen that the Current EVs depends on High Potential Customers and Probability of Purchase. The graph showing the growth of these three variables over the period of 10 years (120 months) is presented in Figure 6. Since the changes in policy over the time period and change in people’s response during those times is not considered here, the growth of EV becomes steady after a certain time. Similar effect could be seen from the saturation of probability of purchase and the peak observed in the high potential customer graphs.

### 6. Conclusion

It was clearly seen from the results that with the choice of policy and infrastructure development from the government side according to consumer preferences, there could be considerable rise in EV in Kathmandu in a short period of time. The rise in number of EVs from 3479 to 950,000 from the start of the simulation to the end (a period of ten years) was a considerable growth regarding the relatively small sample and un-supportive policy status of Nepal. Even though this paper did not implement the changes in policy after certain period of time (since government policy changes continuously based on intermediate status of what the policy affects), high rise in number of EVs was seen vibrantly in the results section. Also, from the survey data, it was inferred that the newer generation (age group 18-35 years) were more interested in buying EVs and
Figure 6: Graph of EV Growth and its Causes

Figure 7: Graph of Willingness to Consider and its Causes
considering this, there could be demographic dividend effect on the growth of EVs in Kathmandu valley too. Hence, using the system dynamics method, the future prediction of EVs based on customer preferences is done in Kathmandu Valley, Nepal.

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