Proceedings of the 2015 International Conference on Operations Excellence and Service Engineering
Orlando, Florida, USA, September 10-11, 2015

A Statistical Approach to Estimate the Correlation between Charging Station Availability and Plug – In Electric Vehicle Sales in Canada

Yassir A. Alhazmi
Department of Electrical and Computer Engineering
University of Waterloo
Waterloo, ON, N2L 3G1, Canada
yalhazmi@uwaterloo.ca

Magdy M. A. Salama
Department of Electrical and Computer Engineering
University of Waterloo
Waterloo, ON, N2L 3G1, Canada
msalama@uwaterloo.ca

Abstract

Using a multiple linear regression model (MLRM), this work estimates the key factors that influence the market sales of Plug-in Electric Vehicles (PEVs). The model attempts to describe the correlation between a response variable and number of explanatory variables by fitting a linear equation to the observed data. Limited information is one of the major challenges that the proposed estimation task faces. For many early adopters, power outlets at home are likely the primary charging facilities in the near term, but many emerging technologies and business models that are under rapid development may also reshape PEV market sales and people's recharging behavior in the longer term. The proposed model determines the key factors among the various factors that jointly influence the dynamics of PEV sales, such as gas prices, electricity rates, available charging infrastructure, vehicle prices, and government incentives. Using historical sales data, the model identifies the correlations between the considered factors and PEV market sales in order to evaluate the key factors that influence PEV sales. A case study of different Canadian provinces is conducted for the period 2016 – 2025 in order to estimate the key factors influencing PEV market sales. Our results, which included the consideration of charging infrastructure availability, are less optimistic compared to the sales forecasts from the literature; hence, more incentive programs should be considered to support investment in charging facilities.

Keywords
Charging Station Availability; Electric Vehicle Charging Stations; Plug–in Electric Vehicles; Multiple Linear Regression

1. Introduction

High oil prices and energy demand are major challenges facing transportation sectors, as reliance on fossil fuels as the main source of energy has negative influences that can affect those sectors. Environmentally, the transportation sector overall produces a large amount of carbon dioxide, adding greatly to greenhouse gas (GHG) emissions. Almost one-third of carbon dioxide emissions in the US come from the transportation sector, according to the U.S. Greenhouse Gas Inventory Report 2011 [1]. In Canada, 35% of energy demand is from the transportation sector, and it is the second-highest source of GHG emissions [2]. Hence, finding alternative energy sources has gained much attention towards filling projected transportation energy demands.

Feeding the energy demand of the transportation sector electrically raises many concerns. The reliability and dependability of plug-in electric vehicles (PEVs) are considered public worries, and the development of PEV technology and infrastructure will play a main role in accepting them. For instance, PEV users want to get rid of their concerns about the limited travel range of PEVs by either having a large PEV battery at a reasonable price, or they want to see dispersed charging stations (CSs) in many public places with quick charging rates in order to enhance convenience and dependability. Almost half of the cost of EVs is due to PEV battery cost [3], so having large PEV batteries will dramatically increase the price of PEVs. On the other hand, electrical CSs will eventually replace gas stations, and investing in PEV charging infrastructure will open new business opportunities for large and small investors. Meanwhile, developing the PEV charging infrastructure will ease some of the EV drivers' anxiety.

The availability of charging infrastructure is a key factor in increasing the acceptance of PEVs at this early stage of adoption. It is normally expected that PEVs will be recharged nightly at home [3], but the limited Electric Range (ER) of PEVs makes public charging a requirement for long-distance trips. Therefore, providing a public charging service as a complement to home charging will be an essential need. Electrical CSs will eventually be dispersed in the network, but inefficient planning for charging infrastructure implementation will hold back PEV adoption. Hence, the implementation of charging stations should be executed with a view to meeting users' and suppliers' needs. PEV users require access to charging stations when they need them, accompanied with a high quality of service. Therefore, a lack of charging facilities due to inappropriate implementation will have a negative impact on drivers' convenience, leading to holding back PEV acceptance, especially in the early stage of adoption.

Investing in premature technology is considered high-risk. Investors desire a profitable business with secure investments that promise maximum profits, so providing a public charging service has to be evaluated with consideration of all uncertainties and parameters affecting that business. One of the key parameters is how big the PEV market will be in the future. Forecasting the future demand for PEVs will enhance investment security, and gives decision-makers and investors the ability to evaluate their investments over the long run.

In the face of the many challenges, forecast information for PEV sales and recharging demand is urgently needed to assess the long-term impacts of PEVs on the distribution system, which could be dramatically more significant than the current impact, which has been unnoticeable. Several existing studies have addressed these issues. One of those studies, conducted by the Pacific Northwest National Laboratory (PNNL) [4], scrutinized PEV market penetration scenarios based on information obtained from the literature and interviews with industry representatives as well as technical experts. Three scenarios, (hybrid technology-based assessment, R&D goals achieved, and the supply-constrained scenario) were presented for the period 2013 – 2045, and the annual market penetration rates for PEVs were forecasted for that period. The results showed that PEV market penetration was forecasted to reach 9.7%, 9.9%, and 26.9% by 2023, and 11.9%, 29.8%, and 72.7% by 2045 for the three scenarios, respectively. An Electric Power Research Institute (EPRI) report [5] estimated new vehicle market shares of conventional, hybrid, and plug-in electric vehicles using choice-based market modeling of customer preferences, and the results showed that PEVs will have market shares of 20%, 62%, and 80% by 2050 in the low-, medium-, and high-penetration scenarios respectively. An Oak Ridge National Laboratory (ORNL) study [6] forecast that the market for PEVs in the US will be approximately 1 million by 2015, which agrees with President Obama's expectation of 1 million PEVs on the road by 2015 [6]. ORNL's Market Acceptance of Advanced Automotive Technologies Model and UMTRI's Virtual Automotive Marketplace Model were utilized in [6] to assess a list of policy options in terms of their potential for improving PEV sales in the next two decades. In a Morgan Stanley report [7], proprietary information was used to forecast sales of hybrid electric vehicles and PEVs, and its prediction was that market demand will reach 250 000 by 2015 and 1 million by 2020. In [8], Gallagher et al. used a multiple linear regression model (MLRM) to estimate how hybrid electric vehicle sales respond to various types of incentives. Their results showed that "a one thousand dollar tax waiver is associated with a 45% increase in hybrid vehicle sales, whereas a one thousand dollar income tax credit is associated with a 3% increase in hybrid vehicle sales." A related recent study in [9] used a sales forecasting model that was based on information about consumer preferences between hybrid electric vehicles and internal combustion engine vehicles, which was extracted from hybrid electric vehicle historical data. A multiple linear regression model was utilized in the study, and it considered some explanatory variables extracted from hybrid vehicle historical sales data with the assumption that PEV market sales would follow the pattern of HEV market sales. Since they used hybrid electric vehicle data, the correlation between charging infrastructure availability and PEV market sales has not been addressed. According to [10], battery range is customers' biggest concern, followed by cost, so our work here is believed to fill the gap in considering charging infrastructure availability. The presented work estimates the correlation between PEV market sales and several explanatory variables, including CS availability, based on the multiple linear regression model. Recent market sales data (2008 – mid-2015) for Plug-in Hybrid Electric Vehicles (PHEVs) and Battery Electric Vehicles (BEVs) and data for the existing charging infrastructure are used in order to estimate the correlation. The data for public charging stations (Level 2 and DC charging stations) have been obtained from the Mogile Tech™ ChargeHub database [11].

The remainder of this paper is organized as follows: Sections 2 and 3 present the Multiple Regression Linear Model (MRLM) and the explanatory variables that have been considered in this study. In Section 4, Canada-wide and three Canadian provincial market sales forecasts have been investigated. Section 5 shows the sensitivity analysis and discussion, and the conclusion of this paper is presented in Section 6.

TABLE I

SUMMARY OF KEY STUDIES IN FORECASTING PEV MARKET SALES [4 – 9]

	Study	Proposed Model	PEV Demand Forecast
1	EPRI (2007)	Choice-based Market Modeling of Customer Preference	Forecast period (2010 – 2050) PEV Rates (2050) $\begin{cases} Low & 20\% \\ Mid & 62\% \\ High & 80\% \end{cases}$
2	PNNL (2008)	Information from the literature and interviews with industry representatives and technical experts using three scenarios: **S1**: Hybrid technology-based assessment **S2**: R&D Goals **S3**: Supply-constrained	Forecast period (2013 – 2045) PEV Rates (2023) $\begin{cases} S1 & 9.7\% \\ S2 & 9.9\% \\ S3 & 26.9\% \end{cases}$ PEV Rates (2045) $\begin{cases} S1 & 11.9\% \\ S2 & 29.8\% \\ S3 & 72.7\% \end{cases}$
3	Morgan Stanley (2008)	Forecast HEV and PEV sales using demographic and ownership data	Forecast period (2010 – 2020) PEVs Rate (2015) 250,000 PEVs PEVs Rate (2020) 1 Million PEVs
4	Duan et al. (2014)	Forecast PEV sales using Multiple Linear Regression Model on HEV sales data (1999 – 2009)	Forecast period (2012 – 2020) PEV Rates (2015) $\begin{cases} Low & 0.25\ M\ PEVs \\ Mid & 0.38\ M\ PEVs \\ High & 0.50\ M\ PEVs \end{cases}$ PEV Rates (2020) $\begin{cases} Low & 0.50\ M\ PEVs \\ Mid & 1.00\ M\ PEVs \\ High & 1.80\ M\ PEVs \end{cases}$

Electric Power Research Institute (EPRI)

Pacific Northwest National Laboratory (PNNL)

2. Multiple Linear Regression Model for PEV Sales Forecasting

In this section, our proposed PEV sales forecast model is described, including the key factors that influence PEV market sales and PEV penetration level (α). The multiple linear regression model is utilized to describe the relationship between PEV market sales as a response variable and several explanatory variables by fitting a linear equation to the observed data. Compared to several existing studies addressing the same issue [4 – 9], our proposed model introduces public charging station availability as a new explanatory variable in the multiple linear regression model, and we consider both BEV and PHEV historical sales data as observed data in our model. Table 1 shows a summary of key previous studies and their methodologies, and Figure 1 shows the comparison of previous studies' output adopted from [9].

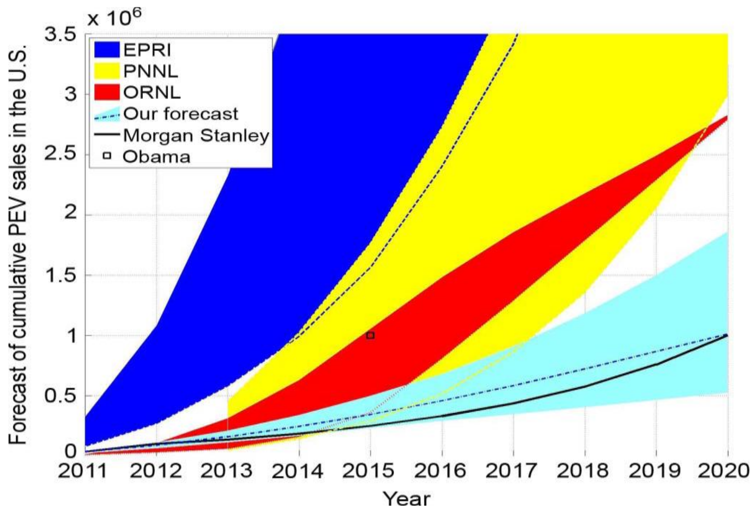

Figure 1. PEV Cumulative Sales Forecast for the U.S. (Adopted from [9])

The following multiple linear regression model is utilized:

$$\log y_k^{PEV} = \beta_0^{PEV} + \beta_1^{PEV} \log x_{k,1}^{PEV} + \beta_2^{PEV} \log x_{k,2}^{PEV} + \cdots + \beta_n^{PEV} \log x_{k,n}^{PEV} + \varepsilon_k^{PEV}, \qquad \forall\ k = 1,2,\ldots, K \quad (1)$$

where

$\mathbf{y_k^{PEV}}$ is the response variable, representing PEV market sales in year (k)

$\mathbf{x_{k,n}^{PEV}}$ are explanatory variables identified to be responsible for PEV sales

$\boldsymbol{\beta_n^{PEV}}$ are the regression coefficients for the explanatory variables, where β_0^{PEV} is the intercept

$\boldsymbol{\varepsilon_k^{PEV}}$ is the error term

An equivalent multiple linear regression model has been used in [12], in which yearly data are utilized to describe electricity demand with regard to several economic indicators. The logarithmic function is used in the proposed model to satisfy the homogeneity of the variance condition of the multiple linear regression model, as stated in [12].

3. Explanatory Variables of PEV Market Sales

Several factors that may potentially influence PEV sales, and accordingly the PEV penetration level (α), including fuel efficiency, gasoline price, vehicle price, average mileage traveled, electricity price, tax incentives, recharging infrastructure availability, manufacturing capacity, etc. In our regression model (1), fuel cost savings, vehicle price, and tax incentives are considered as the three key factors recognized in the literature as the most significant factors on the response variable, HEV market sales [4 – 9]. Since we are studying PEV market sales, we introduce a new factor, public charging infrastructure availability, to the multiple linear regression model as a fourth explanatory variable in order to estimate the relationship between PEV sales and public charging availability. The four explanatory variables that yield the best regression results are explained as follows.

3. 1 Fuel Cost Savings

$x_{k,1}^{PEV}$ is the average fuel cost savings in year (k) over a comparable internal combustion-engine vehicle (ICEV). This variable is computed using the following equation:

$$x_{k,1}^{PEV} = \sum_{m \in M_k} w_{mk}^{PEV} Gas_k TD_k \left(\frac{1}{EF_k^{ICEV}} - \frac{1}{EF_k^{PEV}}\right), \qquad (2)$$

where

$\mathbf{M_k}$ is the set of ICEV models that are considered comparable with the PEV models available in the market in year k

$\mathbf{w_{mk}^{PEV}}$ is the relative weight of the PEV model m (in percentage) to the comparable ICEV in year k
$\mathbf{Gas_k}$ is the average annual gas price in $/L in year k
$\mathbf{TD_k}$ is the average annual vehicle travel distance in km in year k
$\mathbf{EF_k^{ICEV}}$ is the fuel efficiency of the ICEV that is comparable to the PEV model m in km/L
$\mathbf{EF_k^{PEV}}$ is the fuel efficiency of the PEV model m in km/L

The annual average fuel cost savings between the considered PEV models and comparable ICEV models were obtained from Eq. (2). The annual average fuel cost saving is influenced by the annual gas price, the average annual vehicle travel distance, and the weight and fuel efficiency of PEV models compared to the considered ICEV models. The historical and forecast data of these influence parameters can be obtained from Canadian Energy Board [13], and the top three selling PEV models in Canada (Chevy Volt™, Tesla Model S™, and Nissan Leaf™) [14] are compared in this work to the ICEV models Toyota Camry™, Lexus ES 350™, and Toyota Corolla™ [15] respectively.

3. 2 Average Price Difference

The average price difference ($x_{k,2}^{PEV}$) between PEVs and their comparable ICEVs (in $) at year k is investigated. The maturity of ICEV technology compared to PEV technology makes the ICEV price data (historical and forecast) easy to access; however, different parameters can affect the price of PEVs, such as battery technologies, media coverage of PEVs, manufacturing capacity, etc. The price difference between ICEVs and PEVs is assumed in the proposed model to be similar to that in [16].

3. 3 Average Government Incentives

$x_{k,3}^{PEV}$ is the average incentives for PEVs provided by governments in $ in year k. This variable also represents the effect of various other government policies, which cannot all be reflected in a simple regression model. In our proposed model, provincial incentive programs for both PEV purchases and Charging Station (CS) installation are considered. The former is directly applied for PEV sales; however, the latter is indirectly affected PEV purchase decisions. The incentive program data is available in [17 – 19] for different Canadian provinces.

3. 4 Public Charging Infrastructure Availability

$x_{k,4}^{PEV}$ is the public charging station availability (in percentage) relative to gas stations in year k. The explanatory variable newly introduced to the multiple linear regression model for forecasting PEV market sales takes into account the anxiety over limited driving range in the decision to purchase a PEV. The availability of public charging facilities is a key factor in enhancing PEV driving range. Since we estimate PEV sales rather than HEV sales, as has some previous work in the same area, this variable has to be considered in the regression model in order to describe its influence on the response variable, PEV sales.

To forecast PEV sales, we need to obtain not only estimates of these four explanatory variables, but also estimates of the regression coefficients that reflect the influences of the explanatory variables on PEV sales. Due to the limited observable data for PEV sales (2008 – mid-2015), we can only support our estimation of the regression coefficients using HEV sales as a similar technology for the first three explanatory variables. However, for the fourth explanatory variable, public charging station availability, the available data for PEV sales (2008 – mid-2015) is the best that we can obtain currently, but when more PEV sales data are available, that will enhance the accuracy of our fourth coefficient estimates.

4. PEV Sales Forecast Sample Results (2016 – 2025)

In this section, four case studies are presented for the period 2016 – 2025. The first case study was conducted Canada-wide, and we considered the incentive programs provided by different Canadian provinces. The other three case studies covered the three top Canadian provinces in PEV sales, British Columbia (BC), Ontario (ON), and Quebec (QC) [14]. Jointly they are associated with 97% of all PEV sales in Canada for the period 2008 – mid-2015 [14]. The results of the case studies are presented in high, medium, and low projections in order to be consistent with Canadian Energy Board projections [13].

4. 1 PEV Sales Forecast Canada-wide (2016 – 2025)

This case study shows the forecast data for PEV sales in Canada for the period 2016 – 2025 using the proposed MLRM. For the fuel cost savings estimation, we considered the average annual travel distance Canada-wide. Since each Canadian province has its own incentive programs, we considered the average value of three different provinces (BC, ON, and QC) incentive programs. Figure 2 shows the PEV sales forecast for Canada for 2016 – 2025, and the results are demonstrated in both the annual cumulative number of PEV sales and the penetration levels (α_{CAN}). For validation, we compare our penetration level results (α_{CAN}) to the ones presented in [9]; however, we cannot compare the cumulative PEV sales since we consider different geographical areas with different population projections. The results for the reference scenario (α_{CAN}) show that the PEV penetration level is expected to reach 5% by 2024, and total cumulative PEV sales will exceed 1,400,000 by 2025. The penetration level of PEVs in Canada (α_{CAN}) is less optimistic than the one proposed in [9] for the early stages of adoption; however, α_{CAN} will take over during the last couple of years of forecasting based on the reference scenario, and the last four years based on the high case. One important observation is that the number of PEV sales in 2019 is almost doubled in 2020, consistent with the fact that most charging stations permitted or planned are going to be in service by 2020 [11].

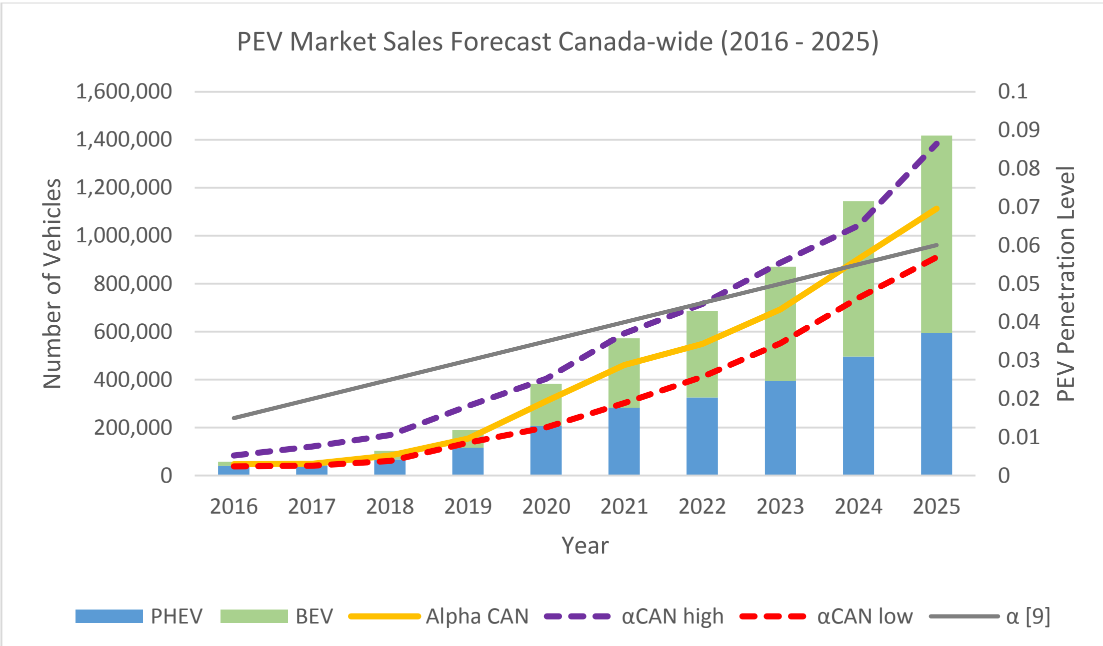

Figure 2. PEV Cumulative Sales Forecast for Canada (2016 – 2025)

4. 2 PEV Sales Forecast for British Columbia (2016 – 2025)

British Columbia (BC) is the westernmost province of Canada. British Columbia is also a component of the Pacific Northwest and the Cascadia bioregion, along with the US states of Oregon and Washington. The largest city is Vancouver, the third-largest metropolitan area in Canada, the largest in Western Canada, and the second-largest in the Pacific Northwest. In October 2013, British Columbia had an estimated population of 4,606,371 [13]. The proposed MLRM has been applied for the observed data for B.C., and the results are shown in Figure 3.

The observed data for PEV sales in B.C. (2008 – mid-2015) show that PEV sales are usually high in the first three months of each year, and then they decline. That is correlated with the fact that the incentive programs are usually stopped after three months yearly due to limits of the B.C. government budget for incentive programs. Therefore, customers will often delay their purchases until the next year in order to be eligible for the incentives. PEV sales in BC started very strong between 2008 and 2011; however, when the number of hopeful buyers exceeds the budget limits of the BC incentive program, and the procedure for getting the incentive is based on a first-come, first-serve basis, which negatively influences sales. The BC government then reduced the incentive to 5,000 dollars in order to approve more applications; however, that decision also negatively affected PEV sales in BC. As shown in Figure 3, the PEV sales forecast for BC is the least optimistic one compared to the other provinces. The forecasted sales are expected to exceed 5% of all vehicles by 2025, which cannot be achieved without the fact that BC has one of the strongest charging station infrastructures in Canada, with a ratio of 1 CS to 3 gas stations in 2013 [11].

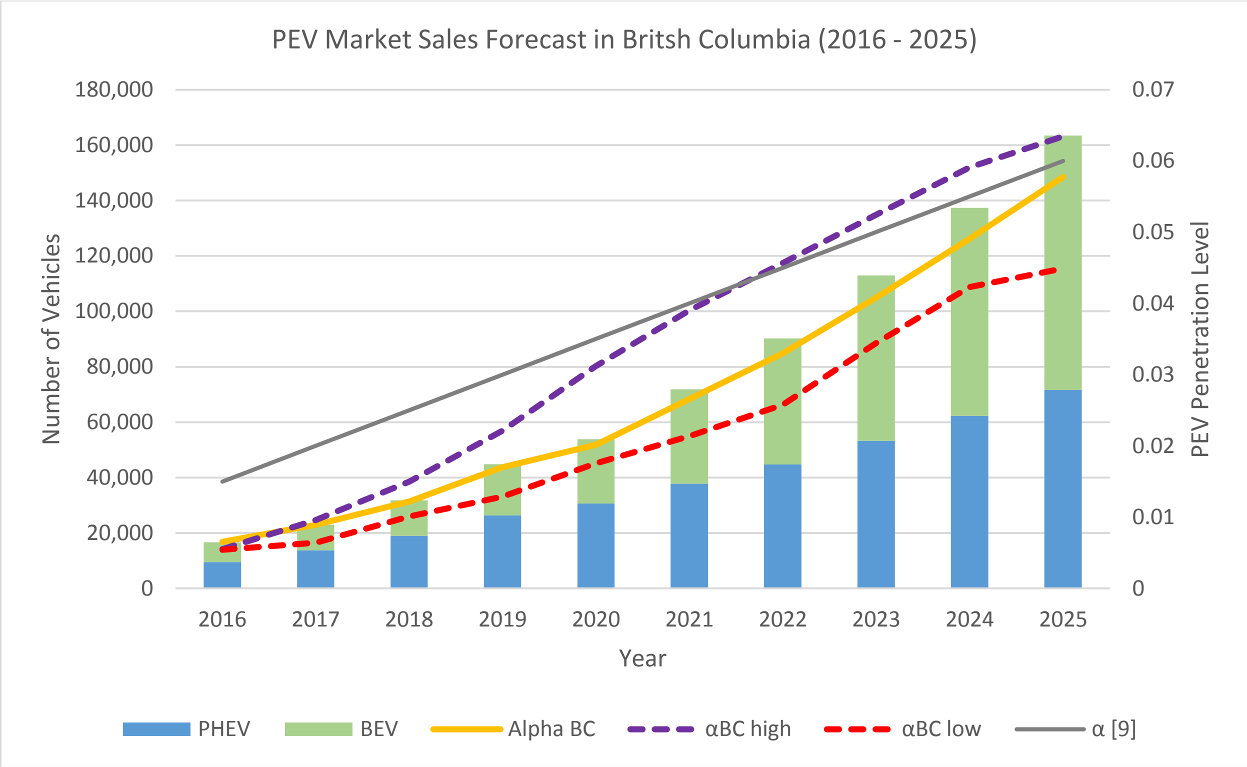

Figure 3. PEV Cumulative Sales Forecast for British Columbia (2016 – 2025)

4. 3 PEV Sales Forecast for Ontario (2016 – 2025)

Ontario is one of Canada’s ten provinces, and is located in the east-central part of the country. It is Canada's most populous province by a large margin, accounting for nearly 40 percent of all Canadians, and is the second-largest province in total area. Ontario is fourth-largest in total area when the territories of the Northwest Territories and Nunavut are included. It is home to the nation's capital city, Ottawa, and the nation's most populous city, Toronto [13]. The large population of Ontario makes it a target for Canadian clean energy projects [13], and the Ontario government has a vision of having 1 in 20 vehicles electrically powered by 2020 [13]. The government of Ontario will be required to take adequate steps for the preparation and development of a province-wide strategy for energy and infrastructure (Ontario Ministry of Transportation, 2010a) [20]. In 2010, the Ontario government announced an incentive program for PEVs of up to 8,500 dollars to buy a new PEV and up to 1,000 dollars to install a home charging facility, but still, public charging station infrastructure is one of the biggest obstacles facing public PEV acceptance. Figure 4 shows the results of applying the MLRM on the observed data for Ontario, and the forecast data show that Ontario’s vision of having 5% of all vehicles electrified is achievable by 2023 in the high scenario and by 2024 in the reference scenario. However, the vision will not be achieved by 2025 based on the low scenario. In order to guarantee that the vision is achieved on time, the Ontario government should take further steps in supporting public charging station infrastructure.

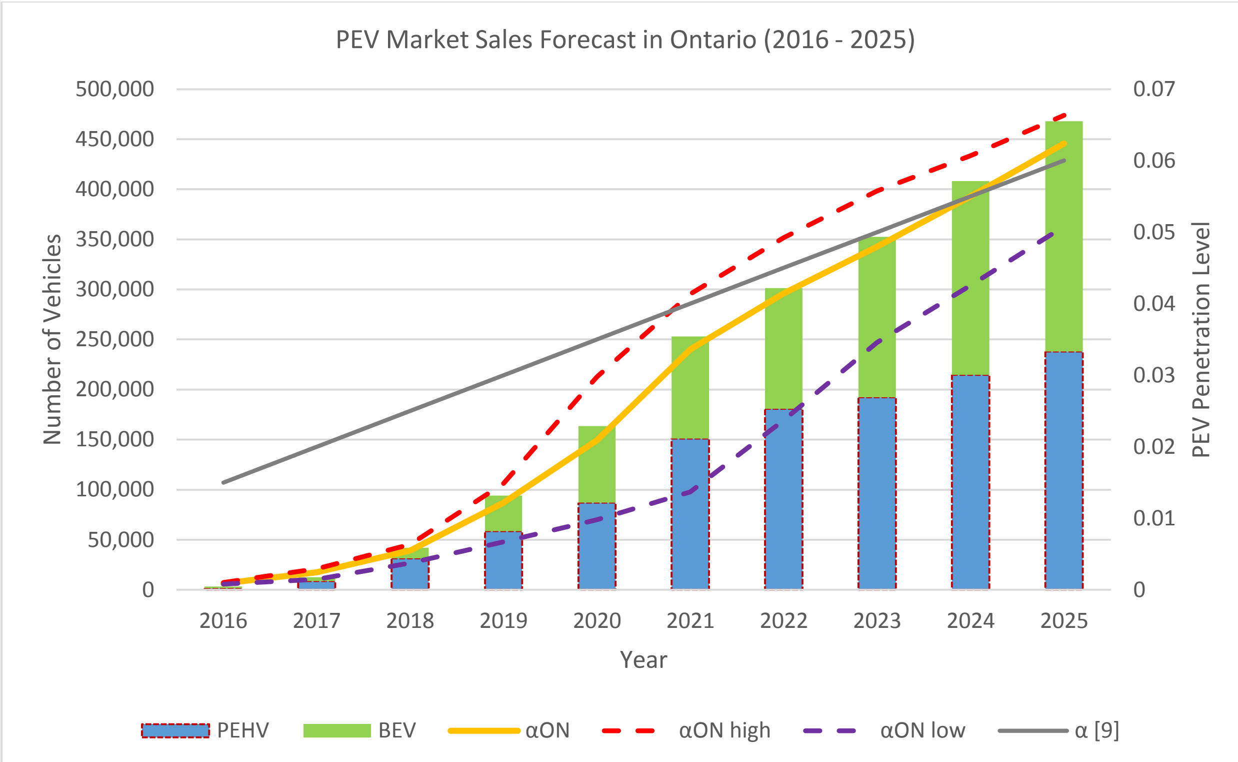

Figure 4. PEV Cumulative Sales Forecast for Ontario (2016 – 2025)

4. 4 PEV Sales Forecast for Quebec (2016 – 2025)

Quebec (QC) is a province in east-central Canada, and it is the only Canadian province that has a primarily French-speaking population. Quebec is Canada's largest province by area, and it is Canada's second most populous province after Ontario. Approximately half of Quebec residents live in the Greater Montreal Area, including the Island of Montreal [13]. The proposed MLRM has been applied to the observed data for Quebec, and the results show that the QC PEV sales forecast is the most optimistic one. The government of QC has taken several steps in supporting charging station infrastructure, and it also supports switching to PEVs through different incentive programs that reach 8,250 dollars per purchase, based on the battery capacity of the PEV. The ratio of charging stations to gas stations is expected to jump to 1:6 by 2025 [11]. One important comment resulting from the observed data is that the government should focus on standardized the charging station ports to make them more convenient for different cars' owners to access the charging network. The challenge in the current charging station network is that Tesla owners should use Tesla chargers, Nissan Leaf owners should use their own charging facilities, and so on. When the charging station network is standardized, it will be easier for any PEV driver to recharge their vehicle across the province. However, this is still a problem with most charging station networks worldwide.

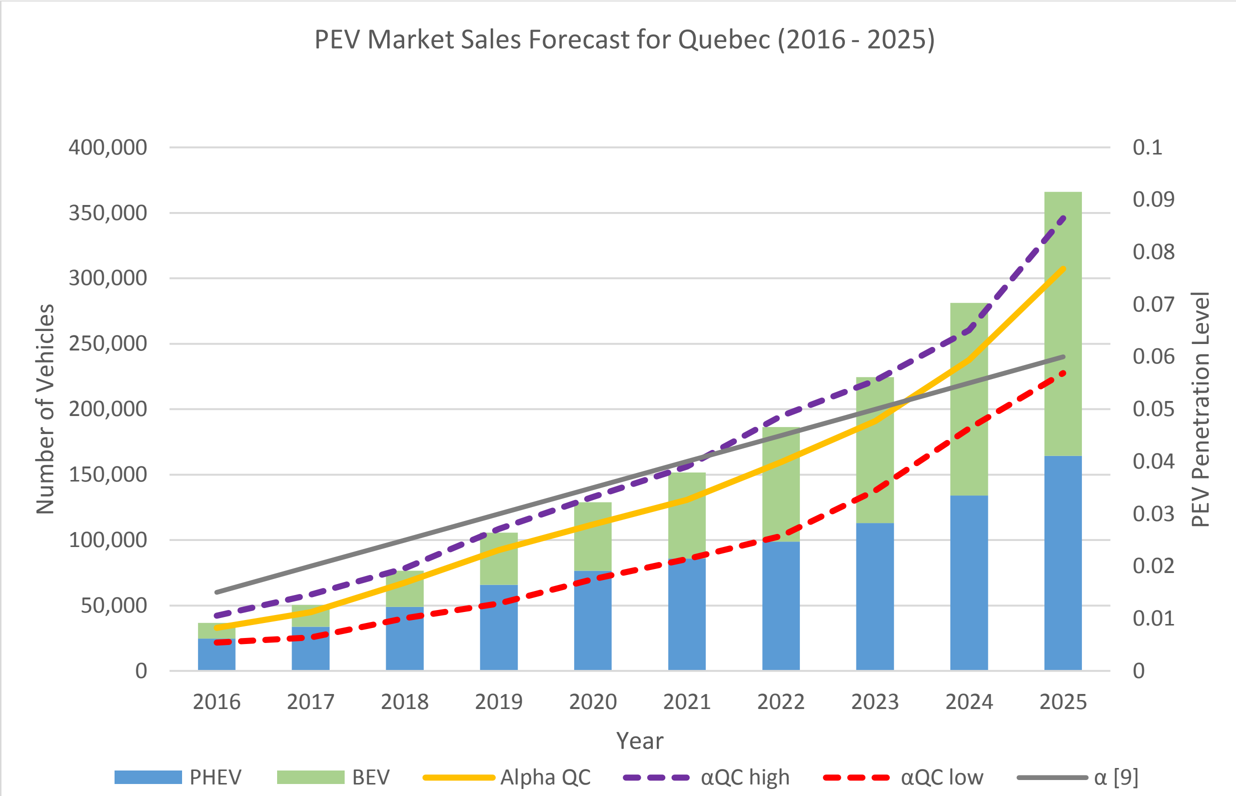

Figure 5. PEV Cumulative Sales Forecast for Quebec (2016 – 2025)

5. Discussion

In this section, some sensitivity analysis is presented to consider different steps that governments can take in order to update their plans for achieving their green transportation goals. First of all, a summary of the MLRM parameters for each provinces as well as Canada-wide is shown in Table 2.

As shown in Table 2, there is an inverse correlation between the average price difference between PEVs and their comparable ICEVs. Therefore, when there is a significant price difference between new PEV models and comparable new ICEV models that will influence potential PEV drivers' purchase decisions negatively. Another observation that can be obtained from the results is that the Ontario government should focus more on charging station infrastructure, so shifting 1,000 dollars from the PEV purchase incentive program to the public charging station infrastructure program will enhance the penetration level of Ontario, as shown in Figure 6.

TABLE 2

SUMMARY MULTIPLE LINEAR REGRESSION MODEL FOR FORECASTING PEV MARKET SALES

	Case Study	Fuel Cost Savings (β_1)	Average Price Difference between PEVs and ICEVs (β_2)	Average Government Incentives (β_3)	Charging Station Availability (β_4)
1	Canada-wide	0.41165	-0.1826	0.1986	0.5182
2	British Columbia	0.4077	-0.1551	0.7718	0.32447
3	Ontario	0.4773	-1.062	0.0176	0.7853
4	Quebec	0.3904	-0.5763	0.0254	0.4253

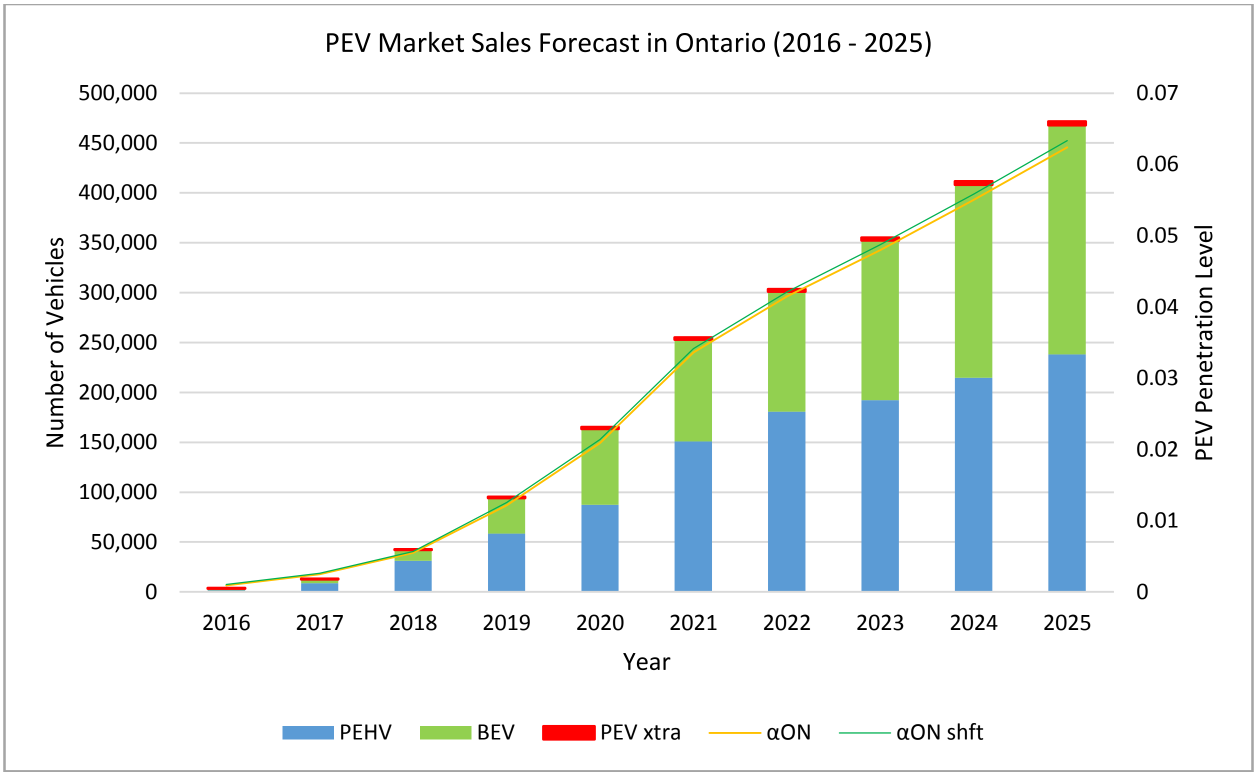

Figure 6. PEV Penetration Level Forecast in the Ontario Shifted Incentives Scenario (2016 – 2025)

In 2013, the ratios of PEVs to charging stations for Canada, BC, ON, and QC are 4:1, 1:1, 7:1, and 5:1 respectively [11]. However, these ratios are expected to be 3:1, 1.5:1, 5:1, and 3:1 by 2025 respectively. These ratios are very useful indicators to evaluate charging station availability on the one hand, and to evaluate the economic benefit of investing in charging infrastructure on the other hand. Hence, Ontario is the best market for investing in charging infrastructure in the next decade, while BC is considered the least secure market to invest in in the next decade due to the high ratio of charging stations there.

6. Conclusion

In this paper, a modified multiple linear regression model has been presented. A new explanatory variable, charging station availability, is introduced to the model in order to investigate the correlation between that variable and PEV market sales forecasts. The proposed model has been compared to a model [9] previously presented in the literature for the sake of validation. Due to the different demographical information in the observed data, the comparison was made for penetration level rather than for cumulative number of PEV sales in order to have a fair comparison. Our forecast results show less optimistic patterns in most cases, especially at the beginning of the forecast period. Some sensitivity analysis and observations have been highlighted to support governments in achieving their green transportation goals. For example, for Ontario, shifting 1,000 dollars from the PEV purchase incentive program to the charging infrastructure incentive program enhances the penetration level by 0.3% by 2025, while preserving the Ontario government's budgetary allowances. The limited observed data for PEV sales (2008 – mid-2015) affects the accuracy of the estimation; however, more accurate estimations can be achieved when more sales data are available.

Acknowledgements

The first author, Yassir Alhazmi, would like to acknowledge the funding support received from Umm Al-Qura University, Makkah, Saudi Arabia, to carry out his research, and Mogile Tech™ and ChargeHub™ for collaboration in providing the required charging station data across Canada.

References

[1] US EPA,C.C.D. U.S. Greenhouse Gas Inventory Report. Retrieved June 25, 2015 from http://www.epa.gov/climatechange/ghgemissions/usinventoryreport.html

[2] Natural Gas Use in the Canadian Transportation Sector Deployment Roadmap. Retrieved June 25, 2015, from http://oee.nrcan.gc.ca/sites/oee.nrcan.gc.ca/files/pdf/transportation/alternative-fuels/resources/pdf/roadmap.pdf

[3] E. Akhavan-Rezai, M. F. Shaaban, E. F. El-Saadany, and A. Zidan, 'Uncoordinated charging impacts of electric vehicles on electric distribution grids: Normal and fast charging comparison', 2012 IEEE Power and Energy Society General Meeting, 2012.

[4] P. Balducci, "Plug-in hybrid electric vehicle market penetration scenarios," U.S. Dept. Energy, Tech. Rep., 2008.

[5] M. Duvall and E. Knipping, "Environmental assessment of plug-in hybrid electric vehicles. volume 1: nationwide greenhouse gas emissions," EPRI, Palo Alto, CA, USA, Tech. Rep., 1015325, 2007.

[6] K. Sikes, T. Gross, Z. Lin, J. Sullivan, T. Cleary, and J.Ward, "Plug-in hybrid electric vehicle market introduction study: Final report," Oak Ridge Nat. Laboratory (ORNL), Tech. Rep., 2010.

[7] M. Stanley, "Plug-in hybrids: The next automotive revolution," Morgan Stanley, Tech. Rep., 2008.

[8] K. Gallagher and E. Muehlegger, "Giving green to get green? Incentives and consumer adoption of hybrid vehicle technology," *J. Environ.Econ. Manage.*, vol. 61, no. 1, pp. 1–15, 2011.

[9] Z. Duan, B. Gutierrez, and L. Wang, 'Forecasting Plug-In Electric Vehicle Sales and the Diurnal Recharging Load Curve', IEEE Transactions on Smart Grid, vol. 5, no. 1, pp. 527–535, 2014.

[10] O. Egbue and S. Long, 'Barriers to widespread adoption of electric vehicles: An analysis of consumer attitudes and perceptions', Energy Policy, vol. 48, pp. 717–729, 2012.

[11] 'ChargeHub | Mogile Technologies.' [Online]. Available: http://www.mogiletech.com/chargehub/. [Accessed: 08-Jun-2015].

[12] I. Azevedo, M. Morgan, and L. Lave, "Residential and regional electricity consumption in the US and EU: How much will higher prices reduce CO2 emissions?," *Electr. J.*, vol. 24, no. 1, pp. 21–29, 2011.

[13] 'NEB - National Energy Board', 04-Aug-2015. [Online]. Available: https://www.neb-one.gc.ca/index-eng.html. [Accessed: 12-Jul-2015].

[14] 'Monthly Plug-In Sales Scorecard.' [Online]. Available: http://insideevs.com/monthly-plug-in-sales-scorecard/. [Accessed: 27-Jul-2015].

[15] New and Used Cars For Sale, Reviews, News, Service', Cars.com. [Online]. Available: http://www.cars.com. [Accessed: 28-Jul-2015].

[16] DOE/EIA, "Annual energy outlook 2011 with projections to 2035," Energy Inf. Admin., Washington, DC, USA, 2011.

[17] L.BC,'Transportation Rebates and Incentives', 30-Sep-2008. [Online]. Available: http://www.livesmartbc.ca/incentives/transportation/index.html. [Accessed: 08-Aug-2015].

[18] G. of Ontario and M. of Transportation, 'Cars are EVolving', 25-Oct-2013. [Online]. Available: http://www.mto.gov.on.ca/english/vehicles/electric/index.shtml. [Accessed: 08-Aug-2015].

[19] 'Electric Vehicles - Site of the Government of Quebec.' [Online]. Available: http://vehiculeselectriques.gouv.qc.ca/english/index.asp. [Accessed: 08-Jul-2015].

[20] A. Hajimiragha, C. Canizares, M. W. Fowler, and A. Elkamel, "Optimal Transition to Plug-in Hybrid Electric Vehicles in Ontario, Canada Considering the Electricity Grid Limitations," IEEE Trans. and Electron, vol. 57, no.2, pp. 690–701, 2010.

Biographies

Yassir A. Alhazmi received his BSc in Electrical and Computer Engineering in 2004 from Umm-AlQura University (UQU), Makkah, Saudi Arabia. He received his MSc in Electrical and Computer Engineering in 2010 from the University of Waterloo (UW), Waterloo, Canada, and is presently working towards a PhD in Electrical and Computer Engineering at the University of Waterloo. His research interests include optimization, power quality, smart grid and Electrical Vehicles (EVs).

Magdy M.A. Salama received his B.Sc. and M.Sc. degrees in Electrical Engineering from Cairo University, Cairo, Egypt, in 1971 and 1973, respectively, and his Ph.D. degree in Electrical Engineering from the University of Waterloo, Waterloo, ON, Canada, in 1977. Currently, he is a Professor in the Department of Electrical and Computer Engineering at the University of Waterloo. His interests include the operation and control of distribution systems, power-quality monitoring and mitigation, and asset management and electromagnetics. He is a registered Professional Engineer in the Province of Ontario.