ecoENERGY Innovation Initiative

Research and Development Component

Public Report

Project: SGSE047-1213 Powering Plug-in Electric Vehicles with Renewable Energy Supply in BC

Contents

1 Executive Summary

Plug-in electric vehicles (PEVs) are a rapidly emerging technology with the potential to enable meaningful Greenhouse Gas (GHG) reductions, especially in BC where transport represents a substantial fraction of provincial emissions: 37% for transportation overall, 14% for passenger vehicles. BC also has a nominally clean generation profile, being hydro-dominant, however the interconnections to Alberta and the US complicate the task of allocating marginal emissions from charging PEVs. The Powering Plug-in Electric Vehicles with Renewable Energy Supply in BC project developed and utilized a range of research methods, across engineering, economic and social science disciplines to assess the GHG reduction potential of personal PEVs on the BC grid, including future renewable generation options. Technical models of stochastic grid operation were used to study the ability for PEVs to help buffer variable renewable generation, and look at systemic emissions from the combined vehicle-grid system. Energy-economy models were used to access policy and carbon pricing on the fleet penetration rates of PEVs. Both of these modeling efforts were informed and used as quantified inputs in a series of interviews, surveys and driving diaries collected in BC to model consumer preferences for vehicle characteristics, driving patterns and preferential clean energy charging. A campus demonstration site including a battery-solar system was augmented with addition PEV charging infrastructure, and interactive kiosks to allow experimentation with messaging queuing to drivers determine their willingness to tailor charging to the availability of clean energy locally and on the main grid. A validation of public charging layout guidelines was undertaken to help best place charging infrastructure throughout BC communities. The outputs of the work have included technical and policy information for BC Hydro and the BC Government to tailor their respective support mechanisms for PEVs to achieve maximal benefits from PEV and charging station rollout in the Province. The project proponents continue to build on this project, expanding the scope from electric, personal vehicles, to include a range of vehicle fleet types and transportation modes, and to access the impact of other fuel types on a transition to an integrated clean grid generation and PEV drivetrains.

2 Introduction

The report documents the project entitled "Powering Plug-in Electric Vehicles with Renewable Energy Supply in BC" funded by the NRCan ecoENERGY Innovation Initiative 2012-2016. The project was led by the proponent, Dr. Crawford, at the University of Victoria (UVic), and involved partners at Simon Fraser University (SFU, Dr. Axsen), the University of British Columbia (UBC, Dr. Meyboom), and the BC Institute of Technology (BCIT Mr. Howey). Non-academic partners included BC Hydro (Mr. Tsang), the BC Ministry of Energy and Mines (MEM, Ms. Ianniciello) and the Pacific Institute for Climate Solutions (PICS, Dr. Pitt). Navius Research Inc. was added as a partner as part of add-on work in 2015/2016.

The overall scope of the project was to examine, from an integrated technical-economic-social perspective, the challenges and opportunities for personal plug-in vehicles (PEVs) in BC. PEVs in this context refer to plug-in hybrid and full battery electric vehicles, for the consumer market, and did not include fuel-cell vehicles or alternative fuel vehicles. Specifically the project looked at consumer preferences towards PEVs, in terms of adoption rates, vehicle characteristic preferences and driving behaviour through a range of social science survey and interview instruments and economic modeling. Through a demonstration project, consumer interaction and preferences with a battery-solar installation on the BCIT campus was examined. Finally, technical analysis of BC's electricity grid was completed, examining the technical impacts of PEVs in BC with models populated by the consumer preference models from the social-economic research activities. Ultimately the goal of the project was to help enable renewable power generators to effectively integrate onto the grid by using PEV's to mitigate the renewable generators' variability in order to provide overall reductions in BC GHG footprint by integrating the transport and electricity sectors and better aligning overall government policy and technology development/deployment.

3 Background

In 2011 when the project proposal was being drafted, PEVs were just beginning to enter the automobile market in British Columbia and elsewhere in significant numbers and as such presented both opportunities and challenges in relation to their energy use and environmental impact. Their environmental benefits relative to conventional vehicles are closely tied to the real-time source of electricity (domestic or imported) used to charge the vehicles. As well, as PEV's enter fleets in larger numbers they may also pose peak-power and grid constraint challenges. However, PEV's may also present an opportunity, as they are a potentially large, deferrable load owing to their on-board batteries and are dispersed throughout the distribution grid. Thus, PEV's also offer a potential avenue for harnessing intermittent renewable electricity sources, such as wind and photovoltaic solar, without the requirement for expensive, dedicated grid-based storage. Understanding how the vehicles will be interfaced with the grid, temporally and spatially, is critical to mitigating the challenges and seizing the opportunities posed by PEV deployment.

BC Hydro, PowerTech and MEM had been operating a BC PEV working group since 2009, of which Dr. Crawford was a member. The activities of that group were directed to facilitating the adoption of PEVs in BC. The Principal Investigators (PIs) at UVic, SFU and UBC were also active over the 2009-2011 period in initial studies around plug-in vehicles from their respective disciplines, including technical grid/vehicle modeling (UVic), vehicle consumer preference (SFU) and charging station design spatial design (UBC). This project was created by combining these strengths into a cross-disciplinary research program, unique in combining modeling and analysis techniques from these disparate academic areas into an effective overall project structure. A parallel demonstration ecoEII project led by BC Hydro resulted in the rollout of an extensive public charging infrastructure for PEVs across BC. The outcomes of the project have been relevant to BC Hydro and MEM in terms of informing their planning and policy to support PEVs, by focusing specifically on the BC context. The adoption of PEVs continues apace into 2017, and as the fleets grow, the outcomes of the project will provide relevant information to the partners on how best to facilitate and further exploit the potential that PEVs represent for GHG reductions.

4 Objectives

4.1 Construct a behaviourally-realistic model of PEV utilization based on the preferences and expectations of early and late PEV adopters including driving, parking and charging behaviour

Two rounds of surveys and interviews were completed by SFU to sample the BC population on attitudes and preferences around PEV purchases and use, and associated renewable power sources. Additional funding outside NRCan was secured for extra social science experiments at UVic during the course of the project. Cluster analysis and revealed preference experiments were used to build models of these consumers suitable for scaling up for future PEV adoption scenarios. The survey and data analysis were completed over the course of the project, building from existing PEV owners to prospective buyers. The analysis of the data yielded quantitative statistical models from sample sizes ~300 to enable generation of driving patterns with associated vehicle and charging preferences. The statistical models could then be used in much larger BC/national scale studies looking at PEV introduction over the next ~ 10 years. This activity directly informed the technical and economic models, serving to link the social research with quantitative projects useful internally to the project for scenario analyses. The results were also utilized by BC Hydro for their planning for PEV adoption.

4.2 Construct a temporally-explicit model of potential renewable electricity supply in British Columbia based on physical, economic and engineering data.

Proprietary data was obtained from BC Hydro on their own and independent power producer (IPP) generation data. Publicly available BC load and interconnection data was also obtained. These datasets were then analysed by UVic and UBC, looking at the temporal connections between generation type (conventional and renewable). This involved various statistical analysis and visualization to understand the complex system dynamics of the monopoly operations of BC Hydro. The data was also used by UVic to inform the development of predictive models of the interconnected BC grid.

4.3 *Utilize the developed models to construct scenarios aimed at optimizing the placement, design and operation of at-home and public charging infrastructure. Real world validation data will be obtained from existing electric vehicle charging stations throughout the province*

UBC had previously completed work for BC Hydro and MEM to develop guidelines for PEV public charging infrastructure. The subtask used analysis of charger utilization as the BC charging stations became live, having used the guidelines to inform their placement, to validate and refine those guidelines. The project was therefore able to support the best placement of charging stations to maximize their utilization, and hence cost-effectiveness, with respect to local community idiosyncrasies. This aspect of the project was unique, in that typically these types of guidelines are developed but almost never verified after implementation in a widespread rollout of infrastructure. The guidelines continue to be useful for the continued implementation of public charger infrastructure.

4.4 *Integrate the demand and supply models to quantify the Greenhouse Gas impacts and the economic costs of strategies and technologies that match intermittent renewable electricity sources with PEV use*

The data on the BC grid was combined with consumer preference data to obtain near-term estimates of GHG emissions associated with PEV use. This work was carried out at UVic and SFU using a range of modeling techniques, from complex stochastic and agent-based market simulations through to simpler marginal generator analysis. The suit of tools was able to simulate a range of scenarios associated with PEV and renewable generation adoption assumptions. Short time scale modeling also allowed for examination of demand response techniques for mitigating renewable generation variability.

4.5 *Adapt the integrated PEV-renewables model to apply to Canadian regions beyond British Columbia, yielding a generic tool useful for low-carbon technology stakeholders and policy makers across the country*

The methodologies, models and scenario studies have been disseminated across a range of partner meetings, technical reports, conference presentations and academic papers. In particular, the multi-disciplinary approach has been shown to provide unique fidelity for taking into account not only technical barriers and opportunities, but properly bounding technical and economic predictive simulations to the social constructs that can limit potential options and deployments. The approach adopted in this project can be replicated across Canada, given the requisite input datasets from the unique grid/market operations, consumer preference differences and regulatory/GHG pricing incentives present in different jurisdictions.

4.6 Develop integrated, long-term policy models for the provinces of British Columbia, Alberta and Ontario using the CIMS modelling framework, working in concert with Navius Inc.

This objective was added to the project in 2015/2016. It leveraged the data gathered on consumer preferences (SFU) and insights into the short time constant constraints on grid operations from the grid-level models (UVic) to refine Navius' economy-wide models of the personal transportation sector. That later model includes a range of cross-connections between policy options, GHG pricing, etc. and was used to simulate a range of scenarios to understand the barriers to widespread adoption of PEVs. In particular, it highlighted the limits imposed by a limited range of class of vehicle (small car vs. SUV) as well as GHG pricing vs. zero emissions vehicle (ZEV) mandates in promoting or stunting the rate of PEV adoption.

4.7 Enhance BCIT's plug-in vehicle charging infrastructure with attached solar generation and on-site battery storage.

This objective was added to the project in 2015/2016. BCIT was able to install interactive kiosks at their battery-solar parking lot installation to enable PEV drivers to preferentially choose charging options based on grid or solar energy. UBC prepared the design of the interfaces to effectively elicit driver interactions. Ultimately this aspect of the project will help future charging infrastructure developers and grid operators to determine the likely attitudes and actions of drivers with respect to the energy sources used to charge their vehicles. This will have implications in terms of overall system operation and GHG reductions, absent large GHG price signals, that might be used to more effectively manage charging.

5 Results of Project

5.1 Project Achievements

The project substantially met its original objectives and was in fact able to expand the scope with additional partner and funds from NRCan in 2015/2016.

5.1.1 Techno-economic-social PEV scenario modeling

At BC Hydro, when the project was being proposed, PEVs were handled within the Office of Chief Technology Officer, as a 'future relevant' technology. Today, PEVs are handled in the operational departments of BC Hydro, and treated similar to other loads coming online. The project was able to help in that progression, by informing the projects of fleet growth and hence load on the system. For the Province, the project was able to support continued development and implementation of targeting support for PEVs, including charging infrastructure and purchase incentives for vehicles and private chargers, including Multiple Unit Residential Buildings (MURBs). The technical modeling was also able to show the potential for demand response to effectively utilize PEVs to support grid operations and renewables introductions. In particular, the stochastic methods were able to show the importance, and tools for handling, variability of PEV loads and generation. The scenario studies including the entire Western Electricity Coordinating Council (WECC) interconnect of which BC Hydro is a part, also highlight the potential of PEV usefulness, but also where it is applicable, i.e. at the sub-hour scale. This is important for technical and policy implantation of charge controls, as well as informing economy-wide modeling at Navius for generation-PEV models construction.

5.1.2 PEV Demonstrations and Deployment

BCIT was able to implement a range of charging infrastructure that was useful during the project, and even more so in the future as larger numbers of PEVs plug-in. The in-house data gathering from those chargers allows for more in-depth understanding of charging behaviour, and the ability to trial options for consumer interactions. This will again inform government and utility policy and development in the direction of PEV support, but can also provide insight to other developers of combined generation/storage micro grids in placing their products in the marketplace in response to consumer demand.

5.2 Benefits

5.2.1 Benefits to Stakeholders

As stated, the project achieved benefits for its stakeholders. At the academic level, the ability to work effectively across disciplines was extremely beneficial for researchers and trained students. Both have gained valuable experience for future projects that is critical to achieving deep GHG reductions, as most technology develop in that direction requires keen attention and integration of technical, social and economic aspects.

For BC Hydro, they gained direct knowledge of PEV consumer preferences that have fed directly into the future load growth and integration planning for PEVs. MEM obtained insights, and a scenario tool, for developing their PEV purchase and charger incentive programs. Benefits to both these partners have large benefits to their operational insights, policy/pricing development, and ultimately cost effectiveness in terms of using PEVs to reduce BC's emissions by integrating clean generation and transportation.
Navius Inc. joined the project and was able to affect model refinement of their generation and transport sub-models, and ultimately provide additional policy relevant results to MEM and national planners.

5.2.2 Benefits to Canada

More broadly, the project has carried out an integrated assessment of PEV options and benefits in BC. The generation mix is BC is unique, especially considering interties to the US and Alberta, and thereby the study has provided an in-depth look at one province that can be extended elsewhere. The demonstration project and grid modeling tools will be further developed to look beyond personal vehicles, as well as to guide renewable deployment. The international market for these services is growing, alongside PEV deployments and national commitments to decarbonize both generation and transportation. Therefore, the lessons learned and methodologies in BC can be extended to other countries to identify the unique potential opportunities that will be created there over the next 5-20 years.

5.3 *Challenges and Barriers*

5.3.1 Student Recruitment & Degree within Project Timeline

As is typical, the project restricted timeline was somewhat challenging in terms of aligning with recruiting graduate students, course requirements and active research terms through the year at some institutions, and timely completion of theses within the project scope. These issues were overcome by active recruitment and scheduling, and did not impact on the ultimate deliverables or outcomes of the project, but are worth mentioning in the context of project and granting structures when incorporating graduate students.

5.3.2 Partner Legal Agreements & Reporting

The time and effort expended in project administration, including legal frameworks with sub partners, etc. was extensive and more onerous than anticipated. Likewise, obtaining materials from partners to populate reporting materials was quite challenging. These were all overcome with additional undocumented efforts, but in future projects overhead administration costs will be incorporated into the budget.

5.4 *Gender Based Analysis*

Phase	Male	Female	Total
Project Planning/Construction/Delivery	3	1	4
Ongoing Operations	7	4	13
Total	13	5	17

6 Conclusion and Follow-up

The project achieved its aims to integrate technical, social and economic research into PEV adoption in BC. Quantitative scenarios have been developed to bound fleet penetration timelines and access the GHG ramifications of charging those vehicles on the interconnected BC grid, both in the near and longer terms. The results have helped BC Hydro to transition PEVs into operational planning integration, and helped MEM develop continued policy and inventive instruments to ensure continued adoption of the vehicles. The project methodology and outputs could be applied by other jurisdictions with their own unique system characteristics to determine their GHG reduction potentials. In the long term, the project has shown both the challenges (effective policy) and benefits (potential for controlled charging and enhanced renewables integration) achievable from integrating the electricity network with electrified transportation for personal vehicles. Ongoing work is building on the project to look at the potential for electrifying all types of ground transportation modes. Ultimately, the project results give direction to utilities and policy makers to best exploit PEVs for overall GHG reductions, as well as to the technology developers of vehicles and charging infrastructure guidance on the large-scale impacts of various design decisions in terms of power balancing and consumer vehicle preferences that need to be addressed for large scale adoption of PEVs.

6.1 Next Steps

The main partners, UVic, SFU and UBC are already working jointly on a follow-up project funded by PICS: “Transportation Futures.” That follow-on project is expanding the scope of the work to multiple modes, from e-bikes to Class 8 vehicle fleets, and also considering alternative energy pathways (biofuels, natural gas, hydrogen) using techno economics. The former work is seeking to electrify many more vehicle types, including assessing the large-scale impacts of autonomous driving and alternative ownership models (e.g. ride-share, co-ops). The latter is a technology agnostic (i.e. not choosing battery-electric drivetrains a priori) assessment of the long-term potential and challenges of other potential fuel pathways, to determine their fundamental economics and energy efficiencies in order to guide policy and technology development efforts best to lower GHG transportation.

In 2017, there are now 10’s of models of PEVs on the market for consumers to purchase. The project highlighted the lack of availability of certain segments (SUV, minivan) which only recently have been addressed by limited market offerings. A key finding of the project was the need for zero emission vehicle mandates to achieve rapid PEV fleet adoption. In addition, controlled charging at super-hour and sub-hour scale was found critical to harnessing the potential of PEVs to support grid operations and renewables generation. Taken together, these findings show that continued federal and provincial policy and support mechanisms are required to speed PEV adoption. Utility interfacing of PEV charging, including pricing, should also be made interactive to achieve maximal benefits. The PEV technology itself will require continued cost decreases in battery pricing, which will be made possible by large-scale manufacture. This in turn is facilitated by rollout of a heterogeneous fleet mix across a wide range of vehicle classes. Finally, the disruptive impacts of autonomous and ownership models of vehicle usage need to be carefully considered, as both are anticipated in the 5-10 yr timeframe and when combined with PEV drivetrains can potentially have both very beneficial (e.g. asset utilization of batteries) and deleterious (e.g. longer commute distances) effects. Here again, policy guidance and regulation will play key roles in facilitative or constraining both the positive and negative potentials of the technologies and business models, not to mention the ramifications social interactions with the transport modes will impose and which need to be better understood.