

Economic Feasibility of the Vehicle-to-Building Concept in the Canadian Context

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Summary

In a simulation study, the economic feasibility of Vehicle-to-Building (V2B) application of electric vehicles (EVs) was determined for building owners and EV owners in Canada. Break-even prices were calculated for various scenarios of building electricity demand profiles, EV battery size, and provincial and environmental conditions, taking into account the impact of V2B on EV battery life. Simulation results showed that sharp peaks in the building load profile and large EV batteries are favourable for V2B economics. Under current conditions, V2B could already break even in the province of Quebec, indicating a clear potential for broader application in the future.

Keywords: V2G (vehicle to grid), case-study, simulation, cost, Canada

1 Introduction

Electric vehicles (EVs) can significantly reduce transportation emissions, especially when they are recharged with power from renewable sources. Many studies have been conducted to quantify the emission reduction potential of EVs in various countries in the world (for instance [1-4]). However, EVs can have additional benefits when they are parked. The battery of the EV can be used as an electricity storage unit for non-driving purposes. EVs could serve as back-up power units that feed power to homes during a power outage (Vehicle-to-Home, V2H), or they could feed power back into the electrical grid (Vehicle-to-Grid, V2G) to assist in stabilizing the electricity grid. EVs could also be used to feed power to a building (Vehicle-to-Building, V2B) during times of peak demands. The application of EVs to reduce the peak power demand of buildings can potentially be profitable for both building and participating EV owners. It could create an additional stream of revenue for EV owners while simultaneously reducing the utility bill for building owners who adopt V2B services.

The concept of V2B has been studied theoretically and experimentally in for instance Japan [5-7]. These studies demonstrated the usefulness of V2B to reduce the peak electricity demand of buildings; however, the effect of V2B on battery degradation was not addressed.

The goal of the study presented in this paper is to investigate the economics of V2B application of EVs in a Canadian context while accounting for the important costs of additional battery degradation due to V2B. This has been done through a simulation study, in which various V2B scenarios were evaluated to determine which factors will affect the V2B economics and if V2B could provide win-win scenarios for both building owners and EV owners.

This paper is organized as follows: Section 2 outlines the methodology used and describes the models and data sets applied in the simulation study. The results for a large number of V2B scenarios are presented and discussed in Section 4. Finally, conclusions on potential scenarios in which V2B will be profitable for both building owner and EV owners are given in Section 5.

2 Methodology

The economic feasibility of V2B in Canadian has been examined by investigating the scenario of employees of an office building using their EVs to supply power to the building to reduce its peak load. The study used electrical data of a typical large office building and different scenarios for the availability of EV battery storage capacity, emulating EV fleets with differing battery sizes. Seasonal influences on the electric load of the building were taken into account and simulations were run for different provinces in Canada to gain perspective on the influence of provincial differences in electricity rates and EV support policies on the V2B economics. Lastly, building electricity load profiles with various peak shapes and different peak reduction requirements have been analyzed to determine the building power demand characteristics that will allow V2B to be successful.

2.1 Electric load profile

Measured building electricity demand data were used to create a base case electric load profile for a large office building of 300 employees. From this base case profile, three other synthetic load profiles were created, which all had the same peak demand, but a different width (duration) of the peak. Figure 1a presents the four electric load profiles used in this study for the summer season whereas Figure 1b presents those for the winter season. The winter profiles have a slightly higher power demand, peaking at 269 kW, while the peak of the summer profile is 242 kW.

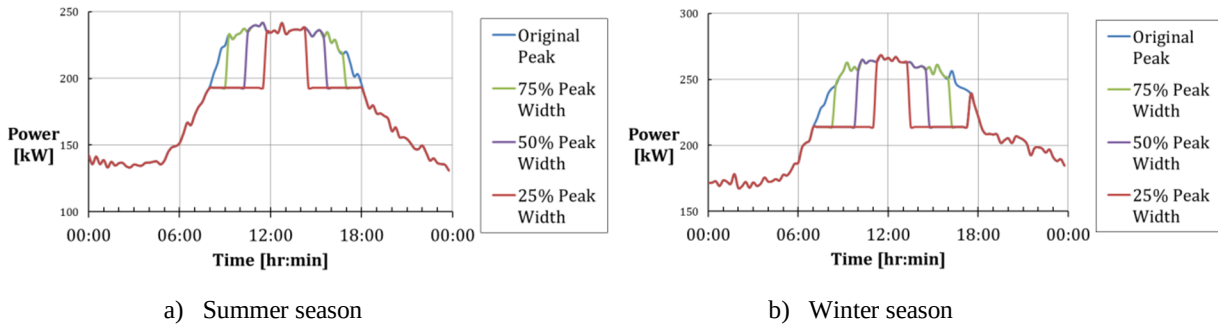


Figure 1: Electric load profiles used for the summer and winter seasons

2.2 Types of EVs

The different types of EVs used in the simulation study and their relevant properties are shown in Table 1. The EVs were assumed to be fully charged at home during the overnight period. Each EV was driven 50 km/day. Additionally, a 30 km ‘reserve range’ was taken into account, allowing the EV owner peace of mind when traffic would be heavier than normal on the way home from work. Only scenarios with uniform fleet composition were considered in this study, i.e. all EVs in a particular scenario had the same electric range.

Manufacturers of EVs generally do not allow EV owners to use 100% of the theoretical capacity of the EV battery, to prevent accelerated degradation of the battery when it is totally full or totally empty. In this study, the usable battery capacity was assumed to be 83.3% of the nominal EV battery capacity. The battery capacity available for V2X varied with the battery size and would be equivalent to 40 – 220 km of driving, using an average driving efficiency of BEVs currently on the market.

Table 1: EV characteristics

EV type	Electric range (km)	Nominal bat. cap. (kWh)	Battery capacity available for V2B	
			(kWh)	(km)
BEV_120	120	24	6.7	40
BEV_200	200	40	20.0	120
BEV_300	300	60	36.7	220

2.3 Economic Model

The two parties considered in the economic evaluation of V2B are the building owner and the EV owners (the employees participating in V2B). V2B was considered to be economically feasible if it was able to generate profit for both these parties. The profit from V2B for the building owner ($P_{V2B,BO}$) depends on the balance between savings from a reduced electricity bill (S_{V2B}) and the revenue paid to EV owners for their participation in V2B (R_{V2B}).

$$P_{V2B,BO} = S_{V2B} - R_{V2B} \quad (1)$$

Electric utilities generally charge building owners for both the amount of electricity used (the energy component) and for the maximum load during a billing period (the capacity component). V2B reduces the charges for both components. The electricity supplied by the EVs to the building (E_{V2B}) does not have to be bought from the utility. More importantly, V2B allows building owners to reduce their peak electricity demand (D_{peak}) and thus lower their capacity charges. The savings from V2B for the building owner are then

$$S_{V2B} = (D_{peak,noV2B} - D_{peak,V2B}) C_{el,kW,BO} + E_{V2B} C_{el,kWh,BO} \quad (2)$$

in which $C_{el,kW,BO}$ and $C_{el,kWh,BO}$ are the rates building owners pay per kW of peak demand and per kWh of electricity, respectively.

Building owners need to reimburse EV owners for their V2B services. The economic model assumes an agreement in which EV owners receive a fixed price ($C_{el,kWh,V2B}$) for every kWh of electricity supplied to the building. The paid revenue to the EV owners is then

$$R_{V2B} = E_{V2B} C_{el,kWh,V2B} \quad (3)$$

For the EV owners, the profit from V2B ($P_{V2B,EVO}$) is determined by the revenue received from the building owner (R_{V2B}) minus the sum of the costs for recharging the EV battery (C_{ch}) and the costs of additional battery degradation from V2B participation (C_{bd}).

$$P_{V2B,EVO} = R_{V2B} - (C_{ch} + C_{bd}) \quad (4)$$

The costs to recharge the amount of electricity supplied in V2B (E_{V2B}) to the EV battery depend on the efficiency of discharging the EV battery to the building (η_{disch}) and of charging the battery at home (η_{ch}), as well as on the electricity rate paid by the EV owner for the electricity ($C_{el,kWh,EV}$)

$$C_{ch} = \frac{E_{V2B} C_{el,kWh,EV}}{\eta_{disch} \eta_{ch}} \quad (5)$$

Two methodologies were used to monetize the impact of V2B on the EV battery life. Method A assumed that the increased battery degradation from participating in V2B will cause the EVs to be discarded earlier. The total capital investment in the EVs (C_{EV}) will thus have to be divided over a shorter vehicle life (L_{V2B}), resulting in an increased cost for the EV owner. Method B assumes the EVs participating in V2B to have the same life (L_{noV2B}) but instead takes the costs of replacement batteries ($C_{repl,bat}$) as the cost of battery degradation.

$$C_{bd,A} = \frac{N_{V2B,bill}}{N_{V2B,year}} \left(\frac{C_{EV}}{L_{V2B}} - \frac{C_{EV}}{L_{noV2B}} \right) \quad (6)$$

$$C_{bd,B} = \frac{N_{V2B,bill}}{N_{V2B,year}} \left(\frac{C_{repl,bat}}{L_{noV2B}} \right) \quad (7)$$

$N_{V2B,year}$ and $N_{V2B,bill}$ are the number of days that the EVs are providing power to the building per year and per billing cycle, respectively. L_{noV2B} and L_{V2B} are the expected life of the EV battery without and with V2B participation. L_{noV2B} and L_{V2B} are outputs of a battery life estimation model, based upon [8]. In this model, the EV battery was assumed to have reached its ‘end of life’ if the battery capacity had been reduced to 75% of the original battery capacity. The battery life model was built-in into the economic model and provided updated estimates of the original EV battery life and battery life under V2B for each evaluated V2B scenario.

It should be noted that the economic model used in this study did not include the infrastructure costs for the building owner to accommodate V2B services from parked EVs.

2.4 Economic Data

The economic feasibility of V2B was investigated for four provinces in Canada: British Columbia (BC), Manitoba (MB), Ontario (ON) and Quebec (QC). Economic conditions differ between these provinces, as they each have their specific electricity rates for business owners and residential customers (see Table 2). All provinces have a similar rate structure for building owners, consisting of a demand charge per kW for the peak load during a billing period, and a fixed rate per kWh consumed. Residential customers only pay per kWh consumed. British Columbia, Manitoba and Quebec have a fixed rate structure for residential customers, while Ontario has Time-of-Use rates. For this study, the off-peak rate for the province of Ontario was used, reflecting that the EVs are recharged overnight.

Table 2: Provincial Electricity Rates (May 2015)

Province	Business		Residential
	Capacity rate (\$cts/kW)	Energy rate (\$cts/kWh)	Electricity rate (\$cts/kWh)
British Columbia	12.41	11.64	12.58
Manitoba	10.33	4.04	8.55
Ontario	10.43	12.27	13.76
Quebec	16.52	4.17	9.89

Another important difference between the provinces is the (non-)existence of incentives for buying an EV. All provinces except Manitoba support the purchase of EVs, though with different amounts (see Table 3).

Table 3: Provincial EV Incentives (May 2015)

Province	EV incentive
British Columbia	\$5,000
Manitoba	\$0
Ontario	\$8,500
Quebec	\$8,000

3 Results

3.1 V2B Scenarios

A total of 144 V2B scenarios were simulated to investigate the impact of various parameters on the economic feasibility of V2B.

The scenarios varied in:

- *the amount of energy required for V2B*: building peak demand reduction of 10%, 20, and 30% were considered,
- *available battery capacity for V2B*: BEVs with 120, 200, or 300 km electrical range were simulated to investigate the impact of EV battery size,
- *the shape of the demand peak*: demand profiles with peaks having 100%, 75%, 50, or 25% of the original office building peak width were evaluated,

- *provincial circumstances*: scenarios for four provinces (BC, MB, ON, and QC) with different electricity rates and EV incentives were run, and
- *building electricity load profile*: summer and winter profiles were used to determine seasonal effects.

Different variants of the economic model were used to evaluate two different costing options to account for the impact of EV battery degradation on the V2B feasibility. All scenarios were based on V2B services provided on weekdays only, as most building owners would likely not require V2B during the weekend.

3.2 Approach to the Results

The results of the 144 simulation cases were compiled and organized to identify notable trends and factors that significantly affect V2B economics. This was done by separately considering the perspective of the building owner and of the EV owners, before looking at the combined results for the V2B scenarios.

The V2B economics for the building owner are linked to the profitability of V2B for the EV owners through the price that the building owner pays per kWh of electricity supplied to the building ($C_{el,kWh,V2B}$ in Eq 3). The economic feasibility of V2B for the building owner was expressed in a break-even V2B rate, i.e. the price per kWh paid to the EV owners that would bring the building owner a zero profit. High break-even prices for the building owner would increase the chance of V2B being profitable. Similarly, the V2B benefits for EV owners were expressed in a break-even electricity rate the EV owners would need to receive from the building owners to balance the costs for recharging and additional battery degradation. In this case, a low break-even price would positively influence the overall V2B economics. When the break-even V2B rate for EV owners would be lower than the rate for the building owners, V2B would be profitable for both parties.

3.3 Building Owner V2B Economics

Simulation results of the V2B economics for the building owner are presented in the following five sub-sections. Each section addresses the impact of the variation of only one or two parameters compared to a base case scenario of achieving a 20% reduction in peak demand of the *original* building electricity demand profile in *summer*, using BEVs with a 300 km electric range in the province of *Ontario*. Only parameters differing from the 5 values given in italics above for the base case scenario are mentioned in the captions of the results tables and figures.

3.3.1 Peak Reduction Requirements

The building owner has the choice to set the level of required peak reduction. Figure 2 displays the break-even rates for the building owner for a 10%, 20% and 30% reduction in the peak demand of the building. Results are given for all provinces considered.

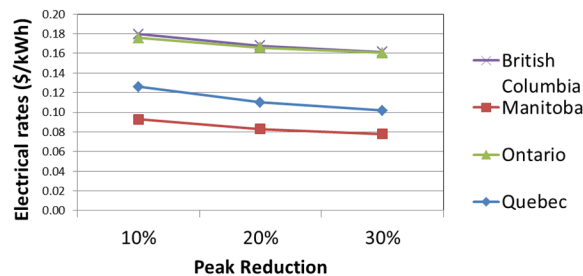


Figure 2: Building owner break-even prices for different levels of peak reduction and for different provinces.

Figure 2 shows that low electricity prices (see Table 2) lead to low break-even prices. For the simulated scenarios, the provincial differences in the costs of the energy component of electricity for building owners

have a much stronger influence on the break-even price than the level of peak reduction, which is correlated to the capacity component of the total electricity costs and influenced by the width of the peak (see Section 3.3.3).

3.3.2 Available Battery Capacity

Simulation results were compared of scenarios employing fleets of EVs with different battery capacities (i.e. different electric ranges). From the results it was observed that the battery capacity of the EV fleet does not have any influence on the break-even price for the building owner, as shown in Table 4 for scenarios having different EV battery capacities and various peak demand shapes.

Table 4: Building owner break-even prices for fleets of EVs having different battery capacities supplying power to a building for different widths of the demand peak.

Peak width	EV type	Break-even price for building owner (\$/kWh)
Original	BEV_120	0.1658
Original	BEV_200	0.1658
Original	BEV_300	0.1658
75%	BEV_120	0.1718
75%	BEV_200	0.1718
75%	BEV_300	0.1718
50%	BEV_120	0.1921
50%	BEV_200	0.1921
50%	BEV_300	0.1921
25%	BEV_120	0.2540
25%	BEV_200	0.2540
25%	BEV_300	0.2540

3.3.3 Peak Width

The effect of the shape of the peak in the electricity demand profile on the V2B break-even price for the building owner is illustrated in Figure 3. The results show a clear increase in break-even prices as the width of the demand peak is reduced. This trend is caused by the fact that the reduction in capacity charges for the building owner only depends on the *level* of peak load reduction, not on the *width* of the peak. A narrower peak will require fewer EVs to attain a certain peak load reduction, allowing the same benefits to be distributed over fewer EVs, thus resulting in a higher break-even price. The province of Quebec has the highest rate for demand charges and consequently the strongest increase in the V2B break-even price for the building owner with decreasing peak width.

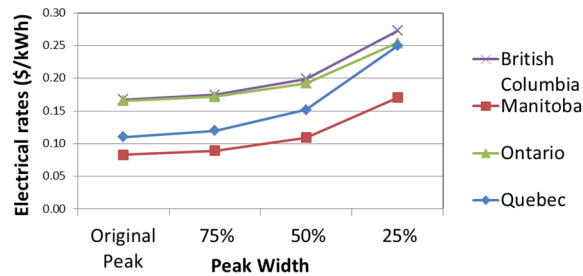


Figure 3: Building owner break-even prices for different peak widths and for different provinces.

Figure 3 further shows that for narrow peaks the break-even price is more strongly impacted by the level of the demand charges, i.e. the capacity component of the electricity costs. This is in contrast with the results for scenarios with the original demand peak width, which indicates the break-even price to be dominated more by the energy component, the per-kWh price of electricity.

3.3.4 Provincial Differences

The differences in the provincial electricity rates strongly influence the V2B break-even price for the building owner. Figure 4 presents the results of scenarios with a wide peak (original peak width), as well as for scenarios with a narrow peak (25% peak width) for all four provinces. Figure 4 illustrates the dominance of the per-kWh cost component in V2B scenarios with wide peaks and the greater influence of the capacity rates in scenarios with narrow peaks.

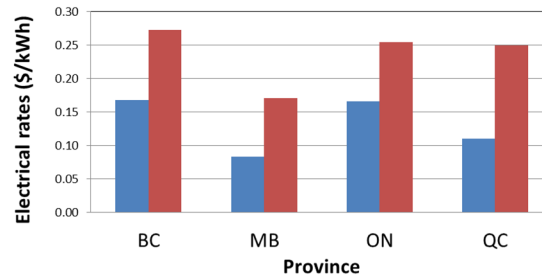


Figure 4: Building owner break-even prices by province for scenarios with electrical demand profiles having the original peak width (left bars in blue) and cases with narrow (25%) demand peaks (right bars in red).

From this comparison, it can be seen that the break-even prices for building owners are highest in British Columbia and Ontario (independent of the peak width) and in Quebec (for narrow demand peak), while Manitoba has the lowest prices for both peak width scenarios.

3.3.5 Seasonal Differences

The impact of seasonal differences in the electricity demand profile on the V2B break-even price for the building owner was investigated by running scenarios for both seasons using the summer and winter profiles shown in Figure 1. Table 5 presents the results for these scenarios for the province of Ontario and various peak widths. Similar results were obtained for the other three provinces.

Table 5: Seasonal comparison of building owner break-even prices for Ontario for scenarios using electricity demand profiles with different peak widths.

Province	Peak width	Summer break-even price (\$/kWh)	Winter break-even price (\$/kWh)
Ontario	Original	0.1658	0.1633
Ontario	75%	0.1718	0.1708
Ontario	50%	0.1921	0.1954
Ontario	25%	0.2540	0.2619

The V2B break-even price in winter is slightly lower than the one in summer for the scenario using the original electricity demand profile. This is a somewhat unexpected result, as the winter profile has the higher peak demand and should therefore receive a higher benefit from a 20% reduction in peak load. The winter demand profile, however, also has a wider peak than the summer demand profile, which results in a lower benefit per kWh supplied to the building.

However, in the scenarios using demand profiles with narrow peaks it was observed that the winter break-even prices were higher than those in the summer scenarios. This is due to the change in the shape of the demand peak, allowing the higher benefits from a larger peak reduction in winter to result in actual higher break-even prices.

3.4 EV Owner V2B Economics

The simulation results of the V2B economics for the EV owner are presented in a similar way as those for the building owner. Each of the five sub-sections addresses the impact of the variation of only one or two

parameters compared to a base case scenario of achieving a 20% reduction in peak demand of the *original* building electricity demand profile in *summer*, using BEVs with a 300 km electric range in the province of *Ontario*. Results are given for both approaches to monetize the additional battery degradation due to V2B: an early discarding of the total EV (Method A), or giving the EV its original life by installing a replacement battery (Method B). Captions of results tables and figures only mention parameters differing from the base case scenario.

3.4.1 Peak Reduction Requirements

First, the influence of the level of peak reduction on the break-even price for EV owners was investigated using the two different methods for calculating the costs of the additional battery degradation due to participation in V2B (see Section 2.3). The simulation results showed that differences in peak reduction requirements had little to no impact on the break-even price for the EV owner (see Table 6). This is because the differences between the three peak reduction scenarios resulted in different *numbers* of EV used to provide the requested V2B, while there were hardly any differences in the *amount of electricity* supplied to the building by each EV.

The numerical results for Method A were identical for all three levels of peak load reduction, while the break-even prices using Method B showed some correlation with the amount of power supplied in V2B. Results were comparable for the other three provinces evaluated.

Table 6: Impact of the level of peak reduction on V2B break-even prices for EV owners.

Peak reduction rate	Method A break-even price (\$/kWh)	Method B break-even price (\$/kWh)
10%	0.3018	0.2881
20%	0.3018	0.2850
30%	0.3018	0.2879

3.4.2 Available Battery Capacity

Scenarios applying EVs with different battery sizes were considered from an EV owner's perspective. The simulation results showed that the application of EVs with larger battery sizes will result in lower break-even prices for EV owners in a given V2B scenario, as illustrated in Figure 5. The reason for this was found in bigger batteries having much lower costs per kWh supplied in V2B for the additional battery degradation due to participation in V2B.

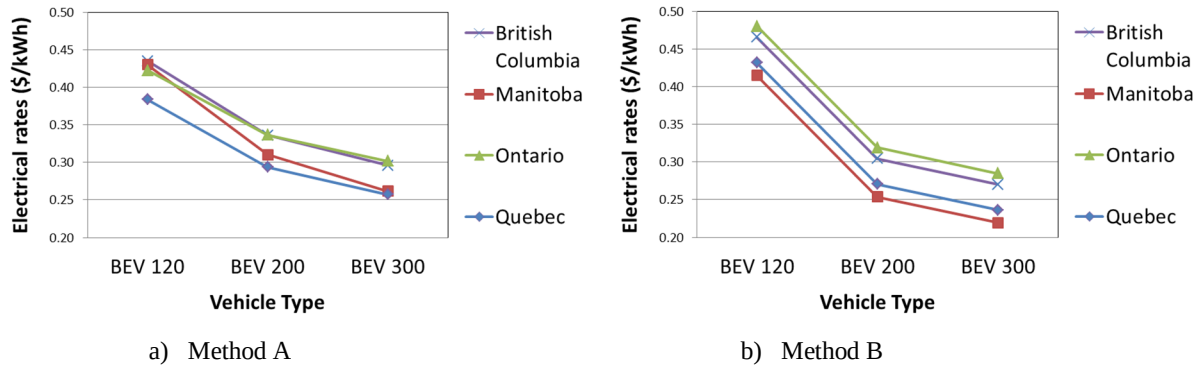


Figure 5: EV owner V2B break-even prices for different battery sizes and provinces using a) Method A and b) Method B for calculating the costs of additional battery degradation due to V2B participation.

Figure 5 also indicates that for EVs with smaller batteries it is generally more economical to discard the EV prematurely when the EV battery reaches its end of life, while for EVs with larger batteries replacement of the battery leads to lower costs per kWh supplied in V2B. The province of Manitoba is the only one of the four provinces evaluated that does not have an electric vehicle subsidy program. The impact of this is seen in the relatively high break-even price for the BEV with the 120 km battery range using Method A. The cost of a

replacement battery is the same for each province. The variation in break-even prices for scenarios of different battery sizes calculated using Method B is therefore identical for each province.

3.4.3 Peak Width

The comparison of the results for scenarios using electricity demand profiles with different peak widths showed that this parameter had little to no effect on the break-even price for the EV owner. Figure 6 displays the break-even prices for scenarios utilizing EVs with different battery sizes in the province of Ontario. Similar to the results for scenarios of different levels of peak demand reduction, the variation of the width of the demand peak will require more or fewer EVs to participate in V2B, but will in general not significantly influence the number of kWh supplied to the building per EV and thus the V2B economics for the EV owner.

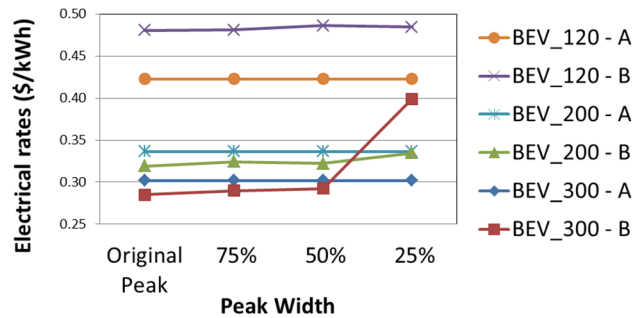


Figure 6: V2B break-even prices for EV owners in Ontario for scenarios employing EVs with different battery capacity and using Method A ('A') or Method B ('B') for calculating the costs of the additional battery degradation of participating in V2B.

This result, however, will change when the peak of the demand profile is so narrow, that EVs involved in V2B will not be able to use a large part of their battery capacity available for V2B. As shown in Figure 6, the scenario utilizing the demand profile with a 25% peak width has a higher break-even price when using Method B for EVs with a 300 km electric range than for EVs with a 200 km range. This scenario requires an average 16 kWh to be supplied to the building by each EV participating, utilizing 80% of the available battery capacity for V2B for the BEV with a 200 km range and less than 45% for the BEV with the 300 km range. In this case, the additional costs for a larger replacement battery cannot be recovered by a correspondingly larger supply of electricity to the building, resulting in a higher break-even price.

Figure 6 also shows an interesting difference between the results for the two calculation methods to account for the earlier 'death' of the EV battery. An early retirement of the BEV (Method A) will lead to lower break-even prices for the EV owner for BEVs with relatively small battery sizes, while Method B (keeping the BEV in operation by replacing the EV battery) was more favourable for BEVs with large batteries.

3.4.4 Provincial Differences

Provincial differences in electricity rates and support programs for EVs result in different break-even prices for EV owners. Figure 7 depicts the results for all four provinces and for both methods of monetizing the costs of additional battery degradation for BEVs with a 300 km electric range. Figure 7 shows that break-even price for EV owners are lower in Manitoba and Quebec and higher in Ontario and British Columbia, regardless of the calculation method used.

3.4.5 Seasonal Differences

Table 7 presents the simulation results for the scenarios using summer and winter profiles for the electricity demand of the building. Similar to the results for the building owner in Section 3.3.5, there was hardly any impact of seasonal differences on the break-even prices for the EV owner. Method A showed identical results for both seasons, while the differences in the results for Method B were minimal.

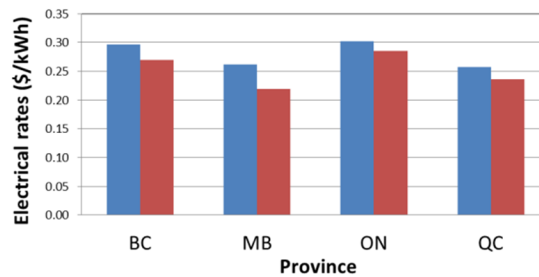


Figure 7: EV owner break-even prices by province using Method A (left bars in blue) or Method B (right bars in red) for a BEV300 fleet using original summer peak data.

Table 7: Seasonal comparison of EV owner break-even prices for EVs with different battery sizes

EV type	Season	Method A break-even price (\$/kWh)	Method B break-even price (\$/kWh)
BEV_120	Summer	0.4225	0.4808
BEV_120	Winter	0.4225	0.4804
BEV_200	Summer	0.3365	0.3245
BEV_200	Winter	0.3365	0.3193
BEV_300	Summer	0.3018	0.2899
BEV_300	Winter	0.3018	0.2850

3.5 Scenarios of V2B Feasibility

The feasibility of the V2B concept was then evaluated by combining the results for the V2B economics for building owner and EV owner. First, an overview was made of the relative influence of the varied V2B parameters in the 144 simulation cases (see Table 8) to help identify scenarios that would be optimal for V2B.

Table 8: Overview of the relative influence of scenario parameters on the V2G break-even prices for building owner and EV owner.

	Break-even price building owner	Break-even price EV owner (Method A)	Break-even price EV owner (Method B)
Level of peak reduction	Minor	no	minor
Available battery capacity	No	strong	strong
Peak width	Strong	no	minor/strong*
Provincial differences	Strong	strong	strong
Seasonal differences	Minor	no	minor

* The influence of the peak width is minor for scenarios in which a large part of the available battery capacity for V2B is used. The impact increases when only a significantly smaller part of the capacity is used.

The ideal V2B scenario is one in which the break-even price for the building owner would be much higher than that for the EV owners. This would for instance be a scenario of a province with a low electric bill for EV owners and a high electric bill for building owners. The building demand profile would be one with a narrow peak while the EV fleet used for V2B has a large battery capacity available and a relatively low cost of the battery degradation due to V2B, because all of the available battery capacity for V2B would be used.

Within the scenarios that were evaluated, only the scenario using the building electricity demand profile with the narrow peak (25% peak width) in the province of Quebec using a fleet of BEV 300 EVs in winter and using calculation Method A (early retirement of EV) was found to have the potential to be economic for both the building and EV owners. This is illustrated in Figure 8. A V2B profit (break-even price for building owner minus break-even price for EV owner) of 0.5 cents/kWh was calculated for this case.

Although the current study only found one scenario with a small V2B profit, the profit has been calculated using realistic prices for EVs in 2015. The price of EV batteries is generally expected to decrease significantly

over the next decade [9], which indicates that there is a clear potential for profitable application of V2B in more applications and provinces in the future.

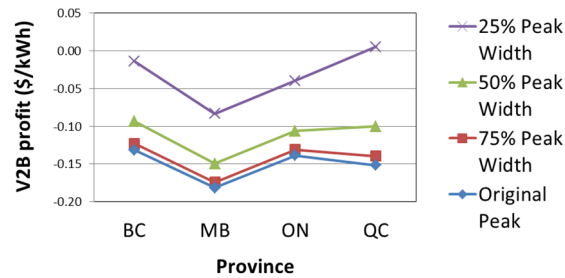


Figure 8: V2B profit (difference in break-even prices between building and EV owners) for various provinces and peak widths for scenarios using BEVs with a 300 km electric range in winter and using Method A.

4 Conclusion

The economic feasibility of using electric vehicles to feed power to a building (V2B) was investigated in a simulation study for various V2B scenarios of an office building in the Canadian provinces of British Columbia, Manitoba, Ontario and Quebec. The application of V2B would reduce the regular electricity bill of the building owner, but the building owner would need to reimburse EV owners for the power supplied from the EVs to the building. Break-even values for the price paid per kWh of V2B electricity were calculated for the building owner and EV owners. Building electricity demand profiles with sharp peaks and high electricity prices for businesses would result in favourable conditions for V2B (i.e. a high break-even V2B prices for the building owner). Break-even prices for EV owners would be lower when residential electricity prices would be low and EVs with large batteries would be applied. The level of peak reduction and seasonal differences in the building demand profiles did not have a strong impact on the break-even prices.

V2B will result in additional battery degradation. The associated costs were taken into account in the simulation study. For EVs with small batteries it would be more economical to discard the BEV at the end of the EV battery life, while the installation of a replacement battery would be more cost-effective for BEVs with large batteries.

The best scenario for V2B would have a relatively high break-even price for the building owner and a comparably low break-even price for the EV owner. For most scenarios, there is a considerable gap between the price building owners would be willing to pay and the V2B revenue EV owners need to break even. However, V2B already breaks even in the province of Quebec for the reduction of sharp peaks using EVs with large batteries. This indicates a clear potential for a broader application of V2B for EVs with cheaper batteries in the future.

Nomenclature

Parameters	Subscripts	Subscripts (cont.)
C Cost	BO building owner	kW per kW
D demand for electricity	bill per billing cycle	kWh per kWh
E Electricity	ch charging	noV2B without V2B
L life of EV battery	bd battery degradation	peak peak
N number of days	disch discharging	repl.bat replacement battery
P Profit	el electricity	V2B V2B, or with V2B
R Revenue	EV EV	year per year
S Savings	EVO EV owner	

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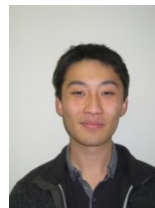
References

- [1] EPRI/NRDC, *Environmental Assessment of Plug-In Hybrid Electric Vehicles. Volume 1: Nationwide Greenhouse Gas Emissions*, Palo Alto, CA, USA, 2007.
- [2] Hajo Ribberink, Chris Shum, Evgueniy Entchev, *The Impact of PHEV Charging on the Future Electricity Grid and on GHG Emissions in Canada*. Proceedings of EV2010VÉ Conference, Vancouver, September 13-16, 2010.
- [3] Jan Hromádsko, Petr Miler, *Environmental benefits analysis of electric vehicles in the Czech Republic*, Transportation Research Part D: Transport and Environment, Volume 17, Issue 3, May 2012, Pages 251-255.
- [4] Xin Zhao, Otto C. Doering, Wallace E. Tyner, *The economic competitiveness and emissions of battery electric vehicles in China*, Applied Energy 156 (2015) 666–675.
- [5] Muhammad Aziz, Takuya Oda, Takao Kashiwagi, *Extended utilization of electric vehicles and their re-used batteries to support the building energy management system*, Energy Procedia 75 (2015) 1938 – 1943.
- [6] <http://www.nissan-global.com/EN/NEWS/2013/ STORY/131129-01-e.html>, accessed on 2016-02-17
- [7] <http://jscp.nepc.or.jp/article/jscpen/20131226/378449/>, accessed on 2016-02-17
- [8] Hajo Ribberink, Ken Darcovich, Fleurine Pincet, *Battery Life Impact of Vehicle-to-Grid Application of Electric Vehicles*, The 28th International Electric Vehicle Symposium and Exhibition, May 3-6, 2015, Korea.
- [9] Björn Nykvist, Måns Nilsson, *Rapidly falling costs of battery packs for electric vehicles*, Nature Climate Change 5, 329–332 (2015)

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