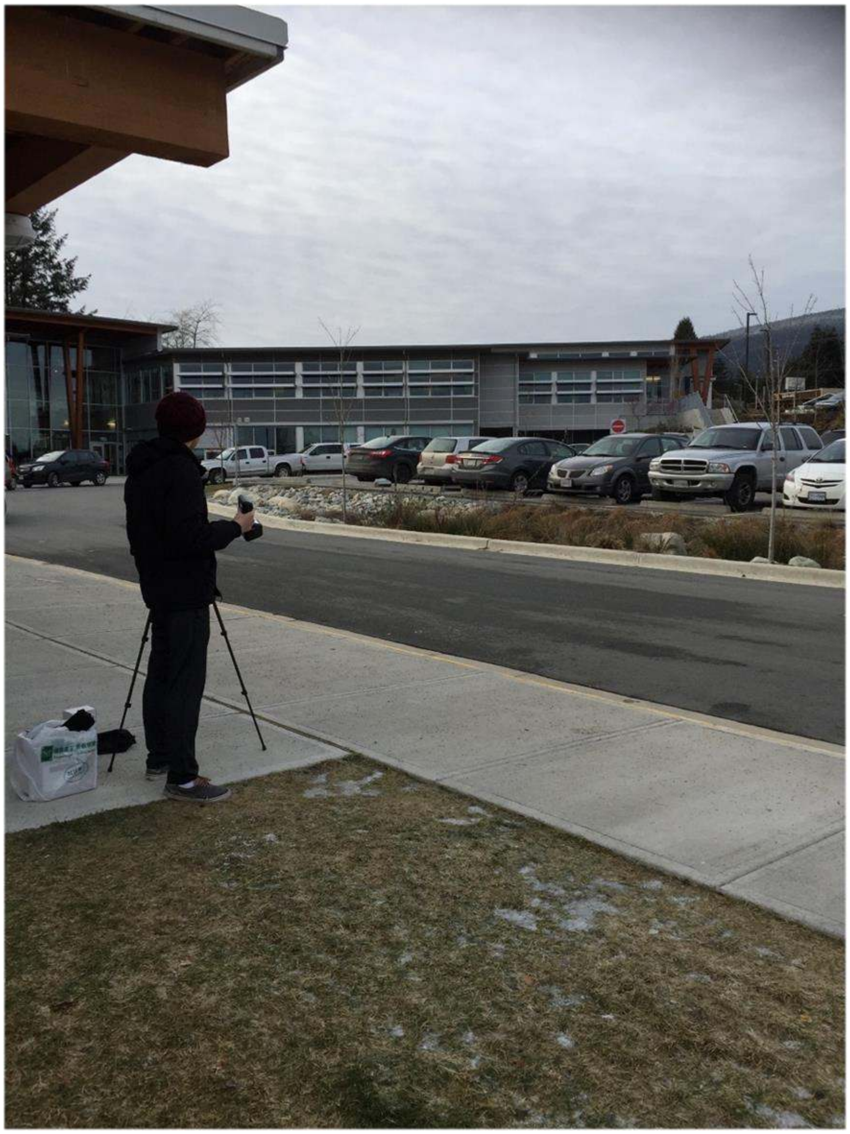
ENVR 400 FINAL REPORT

A School Bus Air Quality Evaluation and A Feasibility Analysis of Converting to Electric from Diesel Buses



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ENVR 400 Community Project in Environmental Science

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Executive Summary

Background

This report is compiled as part of the ENVR 400 community project deliverable to both the Environmental Sciences Department of the University of British Columbia and the Sunshine Coast Clean Air Society (SCCAS). Among miscellaneous atmospheric pollutants, $PM_{2.5}$ officially refers to fine particles with a diameter less than 2.5 µm, which can pose significant threats to the respiratory health of people, especially vulnerable groups like schoolchildren.

The project, proposed by SCCAS, seeks to answer two questions:

1. When commuting on school buses, are schoolchildren exposed to higher levels of $PM_{2.5}$ compared to the ambient level, and the provincial and national standards?
2. How feasible would switching from diesel to electric buses be, based on the costs and benefits between purchasing an electric bus and a diesel bus?

Method Brief

The DC1700 air quality monitoring instrument was used to determine schoolchildren's exposure to $PM_{2.5}$ on board different school buses and at different school stops across Sunshine Coast during the afternoon commutes. $PM_{2.5}$ concentrations are plotted on time series plots based on data logs during the data collection stage in attempt to discover possible correlations between miscellaneous events and significant changes in concentrations. The one-hour average from each sampling trip was compared against the provincial and national air quality standards as a means of determining whether children are exposed to higher or lower levels of particulate matter. An analysis of variance (ANOVA) was also conducted to explore the statistical significance of the difference in concentrations on and off school buses.

As for conducting an appraisal of the feasibility of purchasing an electric bus instead of a diesel bus, a cost-benefit analysis (CBA) using a discounted cash flow method was employed. The values used in the analysis are derived from different sources ranging from scholarly literature, online sources, and the information provided by Thirdwave Bus Company. Three-standard investment decision-making criteria – the present value of aggregate net benefits (ANB), internal rate of return, and discounted payback period – were used to determine whether purchasing an electric bus would be more beneficial relative purchasing to a diesel bus.

Principal Findings

Both the one-hour average on-board and bus-stop $PM_{2.5}$ concentrations were found to be lower than provincial and national standards, but there were times during the sampling period when the standards were exceeded. Overall, there was no clear relationship between logged events – primarily doors opening and closing – and spikes and troughs in our time series plots, which are potentially attributable to factors such as influences from meteorology, number of occupants, and external sources of pollutants. The ANOVA also showed that the $PM_{2.5}$ concentrations on board the school buses were significantly higher than those at bus stops.

The CBA demonstrates positive annual monetary benefits in all years except in year 0 and year 9, when the bus purchase and battery replacement occur, respectively. Overall, purchasing an electric bus instead of a diesel bus yields more benefits since the internal rate of return is above the discount rate, the discounted payback period is below the average lifespan of a bus, and both the public and private ANB are positive. However, based on the sensitivity analysis, this feasibility is highly contingent on the presence of a V2G (vehicle-to-grid) system and low capital cost of electric buses - the two parameters that the ANB was most sensitive to.

Author Biographies

Sylvester Fu

A fourth-year environmental science student minoring in international relations with a focus on economics. Sylvester was responsible for the entirety of the cost-benefit analysis, for external communications, and assisted with part of the air quality analysis and sampling.

Steuart Tannason Ng

Steuart is a fourth-year Environmental Sciences student with interests in urban sustainability. He was responsible for background research on air pollution, design and implementation of $PM_{2.5}$ concentration data collection and data analysis of air quality data.

Wenhao Chen

Wenhao Chen is a fourth-year UBC Science student majoring in environmental sciences with a focus on GIS, remote sensing and cartography. He was responsible for on-board air quality data collection, part of data collection for the cost-benefit analysis and assisted Steuart with visualizing air quality data.

Introduction

The transportation industry has been a major emitter of greenhouse gases and atmospheric pollutants, which affect the socio-economic livelihoods of communities worldwide. Public concerns have surfaced regarding the health effects of atmospheric pollutants, including respiratory and cardiovascular diseases, especially for vulnerable groups, such as elderly and children. It is well documented that combustion from diesel engines can release a considerable amount of $PM_{2.5}$ that is capable of irritating and corroding the alveoli in the respiratory system, causing conditions such as asthma or chronic bronchitis (Environmental Protection Department, 2014). Continual exposure could eventually result in increased hospital admittances and premature mortality (acute responses), as well as reduced life expectancy in cities with higher pollutant levels (chronic responses).

Indeed, children are exposed to higher risks of asthma exacerbation, decreased lung function, and immunologic reactions because of exposure to diesel exhausts from school buses (Mazer, Vann, Lamana, & Davisoin, 2014). In the study of Washington State school buses by Adar et al. (2008), the researchers found that the average concentrations of $PM_{2.5}$ on board the school buses were up to four times higher than ambient levels. Their findings also revealed that some in-cabin particulate concentrations originated from the buses' own emissions.

With these health effects in mind, schoolchildren who rely on School District 46's (SD46) bus service, provided by Thirdwave Bus Services, may have been exposed to routinely high levels of atmospheric pollutants from the diesel combustion during bus operations. If students in the district are breathing in substantially higher levels of $PM_{2.5}$ on current diesel-powered school buses than the provincial and national air quality standards, they could be exposed to routine threats to their respiratory health.

Thus, the Sunshine Coast Clean Air Society (SCCAS) would like an assessment of the schoolchildren's $PM_{2.5}$ exposure and the feasibility of phasing out diesel school buses in favour of electric buses due to their lower $PM_{2.5}$ emissions. Conventional diesel buses have been notorious for the highly-concentrated pollutants they emit. In 2004, a study by Wayne et al. pointed out that compared to conventional diesel buses, hybrid-electric transit buses generate substantial $PM_{2.5}$ reductions. Additionally, Cooney et al. (2013) concluded that electric buses have lower $PM_{2.5}$ emissions than conventional internal combustion engine buses.

To meet SCCAS's goals and to further their mission, this project has two primary objectives:

1. To determine whether SD46 schoolchildren are exposed to particulate matter concentrations that are higher than ambient levels, as well as the provincial and national standards.
2. To assess the feasibility of switching the diesel-powered school buses of School District 46 of Sunshine Coast to electric powered school buses.

To meet the first research objective, air quality samplings have been conducted across different bus routes and bus stops across SD46 to investigate children's differential $PM_{2.5}$ exposures on the buses compared to when waiting at the bus stops.

As for the second research objective, a cost-benefit analysis (CBA) was employed to determine whether purchasing an electric bus would generate more benefits than purchasing a diesel bus, based on a set of investment decision-making criteria. The more benefits that an electric bus would accrue, the more feasible and justified a gradual conversion to electric buses would be.

Initially, a third component of our project was to review the efficiency of current school bus routes in terms of ridership and potential strategies to optimize future routes. However, after extensive consultations between our team, SCCAS, and SD46 in late November 2016, we concluded that the limited timeframe of our project would prevent us from delivering an accurate and comprehensive study given the complexity and demand for resources of this research topic. Thus, this component has been permanently excluded from the scope of this project.

Air Quality

Methodology

Six different routes out of fourteen school bus routes and six different bus stops corresponding to different schools were selected to be sampled. Air quality sampling was conducted only in the afternoon when school buses were sending schoolchildren home since acquiring morning measurements posed a logistical challenge for the team which does not reside at the Coast: per the B.C. Ferries website, the first ferry from West Vancouver to Sunshine Coast departs at 07:20 AM, while the school buses generally leave the bus depot between 07:00 AM and 07:40 AM.

Starting time	Ending time	Bus Route	School Stop	Date
02:35 PM	03:39 PM	281	Langdale Elementary School	January 6th, 2017
02:37 PM	03:52 PM	189	Cedar Grove Elementary	January 9th, 2017
02:53 PM	03:44 PM	290	Robert's Creek Elementary	January 11th, 2017
02:47 PM	04:01 PM	289	Gibsons Elementary	January 13th, 2017
03:01 PM	04:01 PM	287	Chatelech Secondary	January 18th, 2017
02:34 PM	03:49 PM	232	Davis Bay Elementary	January 20th, 2017

Table 1: Details on sampling dates, starting and ending times of data collection, bus route numbers and schools.

Therefore, data collection was completed on six separate days throughout January 2017. The instrument for determining $PM_{2.5}$ concentrations was the DC1700 Air Quality Monitor developed by Dylos Corporation. Since the DC1700 measures particulate number concentration (PNC), the data had to be converted to μg/m^3 using the formula provided by Steinle et al. (2015):

$$PM_{2.5} = 0.65 + 4.16 \times 10^{-5} \times [PNC] + 1.57 \times 10^{-11} \times [PNC]^2$$

Even then, the DC1700 only measures the PNC values of particulates of two size classes with an aerodynamic diameter greater than 0.5 and 2.5 μm, respectively. The PNC values of particulates greater than 2.5 μm were deducted from those greater than 0.5 μm, thus resulting in the PNC values of particulates less than 2.5 μm and greater than 0.5 μm. These PNC values were then converted to μg/m^3 using the above formula. Therefore, since the differences between the PNC of these two size classes are calculated to determine $PM_{2.5}$, the $PM_{2.5}$ defined in this study is likely an underestimation as it does not capture the resolution below 0.5 μm.

Two DC1700 instruments were used, as measurements were taken on the buses and at the school bus stops at relatively concurrent times. The $PM_{2.5}$ measurements were automatically logged as per-minute concentration averages into an appropriate software that was downloaded prior to data analysis.

Figure 1: The Dylos 1700 air quality monitor

To capture any variability due to the specific sampling locations on the bus, air quality measurements were taken at different micro-locations on-board the bus. For two of the bus routes – #281 and #189 – sampling was conducted at the back of the bus to reduce the influence of increased $PM_{2.5}$ concentrations when the bus door opens. For Routes #290 and #289, sampling was conducted at the middle of the bus, whilst for the remaining two routes #287 and #232 it was done at the front. Therefore, for the total of 6 bus routes being studied, each micro-location was sampled twice.

Various factors that may affect the readings, such as instances of doors opening and closing, were logged alongside the air quality measurement. Open doors provide a pathway through which pollutants outside can enter the bus when the in-cabin air mixes with outside air. Other factors qualitatively noted include whether windows are open or closed and the number of occupants. The data collection started once the first student boarded the bus, and ended once the last student disembarked.

Meanwhile, the $PM_{2.5}$ concentrations on the school ground were assessed to determine the exposure of students to particulate matter while waiting for the school buses. The sampling durations for both on the bus and at bus stops approximate to an hour in length, thus the average for the whole sampling duration would be denoted as a one-hour average.

In addition, the $PM_{2.5}$ concentrations at the school stops are assumed to be the ambient concentrations on their respective days. The rationale behind this is that monitoring stations across the Coast are spread out and do not necessarily capture the local-scale $PM_{2.5}$ concentrations specific to an individual school – which may be quite far from the closest monitoring station. Thus, bus-stop concentrations at the school grounds are a better approximation of the ambient $PM_{2.5}$ level that children are exposed to.

To synthesize $PM_{2.5}$ data in a more understandable format, Microsoft Excel was used to plot graphs of $PM_{2.5}$ concentrations over time for each sampled bus route. The time intervals when the buses arrive and depart from major school bus stops, corresponding to prolonged periods of doors opening and closing, are displayed on the time-series graphs. The resulting time series graphs show the times at which the sampled routes had the highest and lowest one-minute averages, as well as when there were drastic changes in $PM_{2.5}$ concentrations. We assume that meteorological factors did not have a significant effect on concentrations on the bus since the bus windows were closed during the winter, although this was not assumed for outdoor sampling at the bus stops. A box plot graph was created to display the distribution of $PM_{2.5}$ concentrations, including median values, upper and lower quartile, which allows for a comparison between $PM_{2.5}$ concentrations on the bus and at the school stops.

An ANOVA was also conducted to compare the overall $PM_{2.5}$ concentrations on the school buses and at the school bus stops. With a significance level of 5%, the ANOVA enabled the determination of a significant difference between the exposure of school students to $PM_{2.5}$ when they are aboard the buses and on the school ground.

The air quality measurements were compared to the Provincial Air Quality Objectives (AQO) and Canadian Ambient Air Quality Standards (CAAQS). The standards as of 2017 are as follow:

1. Provincial AQO: 24-hour averages of 25 $\mu g/m^3$ for $PM_{2.5}$
2. CAAQS: 24-hour averages of 28 $\mu g/m^3$ for $PM_{2.5}$

Results

A box-and-whisker plot (Figure 2) shows the distribution of pollutant concentration both on the buses and at the bus stops. The plot is based on the collective data for all sampling dates, rather than on an individual day.

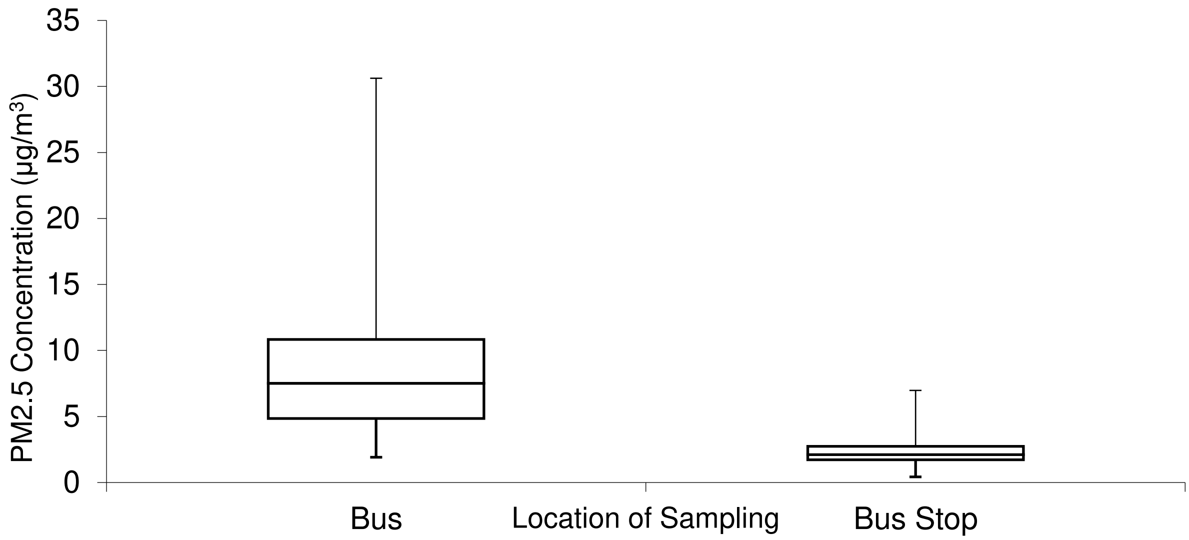

Figure 2: A box-and-whisker plot showing the distribution of $PM_{2.5}$ concentrations with various statistical parameters: 1.5 + upper quartile (Upper Whisker); upper quartile (top line of the box); median (middle line of the box); lower quartile (bottom line of the box); lower quartile - 1.5 (bottom whisker). Outliers are discarded because one of the values is considered too extreme; the maximum recorded value is 186 μg/m^3 for bus data)

As illustrated in Figure 2, the median average per-minute concentrations of $PM_{2.5}$ are higher on the buses that the school stops; the median concentration of both sets of data – 7.5 μg/m^3 across all buses and 2.1 μg/m^3 across all school stops. The interquartile range across all school buses (4.8 to 10.8 μg/m^3) is also larger than that of the school stops (1.7 to 2.7 μg/m^3).

More importantly, the measured $PM_{2.5}$ concentrations are compared to the Provincial and Canada-wide air quality standards: 25 μg/m^3 and 28 μg/m^3. The average concentrations across all sampling trips for both aboard buses and at the school stops are 10.8 μg/m^3 and 6.6 μg/m^3 respectively, which are well below the official standards. The ANOVA reveals that these differences are statistically significant (See Appendix VII); the overall P-value is significantly lower than the 5% alpha level.

Due to transportation challenges, the data collection was limited to afternoon commutes. The following time series graphs show the concentration trend of $PM_{2.5}$ over the duration of sampling:

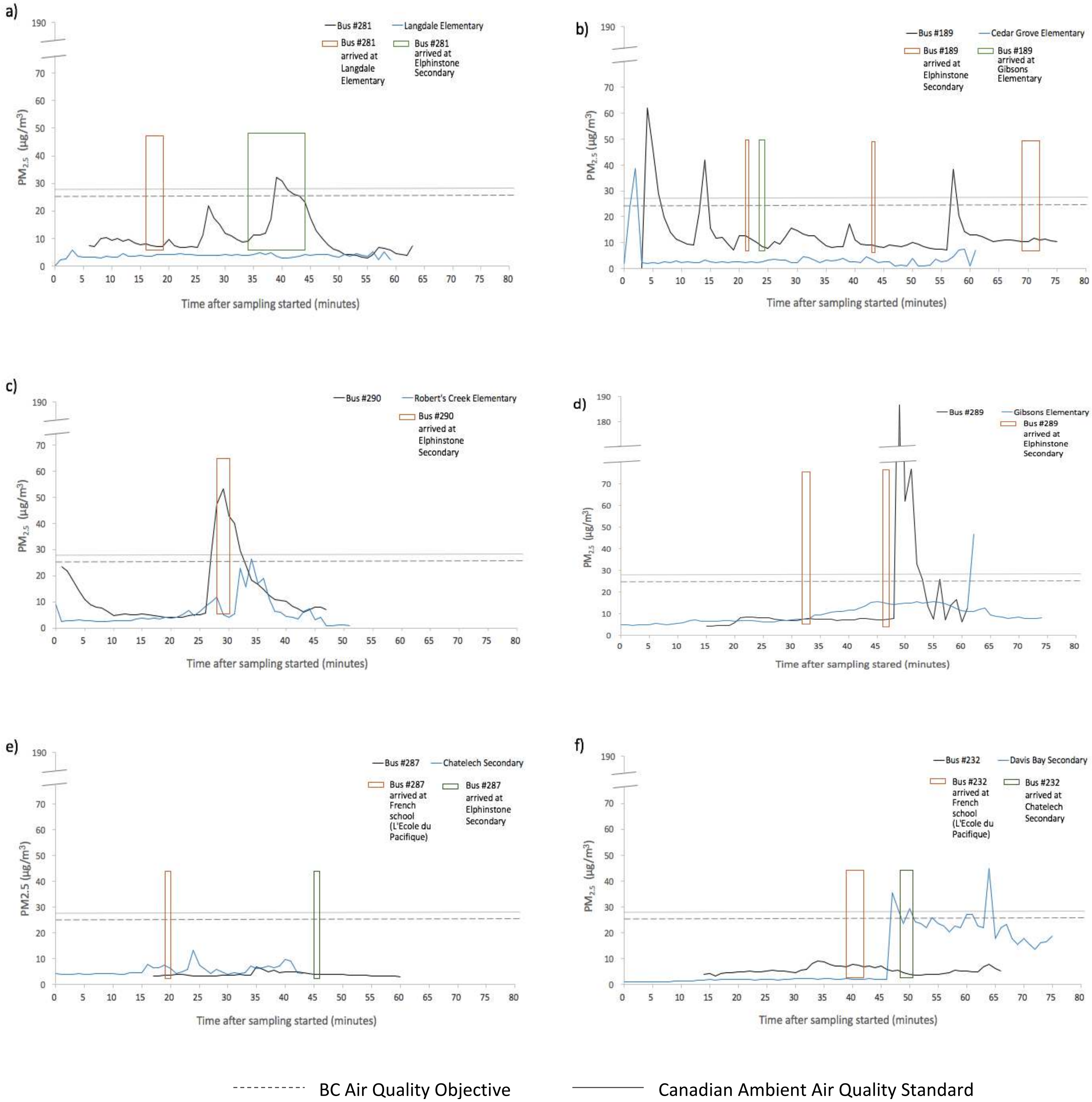

Figure 3: Time series graphs of $PM_{2.5}$ concentrations on a) bus route #281 and Langdale Elementary on January 6th; b) bus route #189 and Cedar Grove Elementary on January 9th; c) bus route #290 and Robert's Creek Elementary on January 13th; d) bus route #289 and Gibsons Elementary on January 18th and; e) bus route #287 and Chatelech Secondary on January 18th; f) bus route #232 and Davis Bay Secondary on January 20th. The x-axis is displayed as the time (minutes) that had passed after DC1700 was turned on at the school bus stops. The instances of bus arriving and departing from schools, as well as the provincial and national standards, were also plotted.

Bus Routes	1-hour Average Concentrations of $PM_{2.5}$ (µg/m^3)	School Bus Stops	1-hour Average Concentrations of $PM_{2.5}$ (µg/m^3)
281	10.6	Langdale Elementary	3.7
189	14.1	Cedar Grove Elementary	3.7
290	13	Roberts Creek Elementary	5.8
289	16.1	Gibsons Elementary	9.3
287	4.0	Chatelech Secondary	5.6
232	5.5	Davis Bay Elementary	9.8

Table 2: Summary of the 1-hour average concentrations of $PM_{2.5}$ across all buses and school bus stops at Sunshine Coast.

The one-hour average $PM_{2.5}$ concentrations were higher on-board the buses on four sampling days: January 6th, January 9th, January 11th and January 13th (see Table 2), but all one-hour averages were below the official standards. Despite being below the official standards, there were moments during sampling when $PM_{2.5}$ concentrations exceeded the minimum allowable standard (Figure 3). For instance, in-cabin measurements on Bus #290 on January 11th indicate an increase from 5.6 to 47.2 µg/m^3 within just two minutes – thus exceeding both the British Columbia Air Quality Objective and Canada Ambient Air Quality Standard. This occurred 26 minutes after the DC1700 was first switched on at Roberts Creek Elementary.

A similar trend was observed on Bus #189 on January 9th and on Bus #290 on January 13th. On these days, there were occasional exceedance of standards. They are generally characterized by a rapid increase of $PM_{2.5}$ within a short duration of time. These sudden increases in concentration are accompanied by relatively gradual decreases to a level near their former values (Figure 3b and 3c). For example, Figure 3b shows the concentration peak 13 minutes after the DC1700 was turned on, although the concentration eventually dropped to 11.5 µg/m^3.

An unusually high $PM_{2.5}$ concentration spike was observed on Bus #289 on January 18th (Figure 3d); the $PM_{2.5}$ concentration rose to 186.5 µg/m^3 49 minutes after the DC1700 was turned on – more than a 20-fold increase within 1 minute. Presumably, this data point is an outlier, although the same may not apply to other exceedances of the standards.

In the time series graphs, no clear relationship between concentration peaks of $PM_{2.5}$ and instances of prolonged doors opening (and closing) at the school stops was observed since the $PM_{2.5}$ peaks does not match the logged instances of door activity. For instance, on January 6th, the $PM_{2.5}$ concentration peaked at 23 µg/m^3 10 minutes after the Bus #281 arrived at Langdale Elementary School (Figure 3a). Despite the observed increase in concentration as Bus #281 arrived at Elphinstone Secondary, it had declined before the bus departed. The concentration was expected to stay at relatively high concentration as long as the bus door was open. Similarly, on Bus #189, the in-cabin concentration peaked on several occasions before the bus reached its first major stop, Elphinstone Secondary, 21 minutes after departure (Figure 3b).

Table 2 presents the relative differences in $PM_{2.5}$ concentrations between the school stops. They range from 3.7 to 9.8 µg/m^3 and these differences are dependent on the meteorological conditions and exact locations of the schools. For instance, Gibsons Elementary and Roberts Creek are situated right beside the main roads, which might lead to higher concentrations of $PM_{2.5}$. In contrast, the concentration at Langdale Elementary School was low, likely due to its remoteness and distance from major urban activity compared to other schools.

Considering meteorological conditions, the one-hour average $PM_{2.5}$ concentration in Cedar Grove Elementary was lower than expected (since the school was located beside a main road). It might be due to the light rain that occurred during time of measurement, which can cause particulates to settle down onto the ground. However, other sampling days were conducted at similar weather conditions – mostly sunny.

In addition, the one-hour average concentrations on January 18th and January 20th were higher at the bus stops compared to those at the school stops (Table 2). At Chatelech Secondary, the difference was due to the simultaneous presence of six school buses at the start of the measurement, thus contributing to relatively poor air quality on the school ground.

In contrast, the $PM_{2.5}$ concentrations were lower at the bus stop of Davis Bay Elementary than on Bus #232 – up to 46 minutes after DC1700 was switched on (Figure 3f). It increased from 1.8 µg/m^3 to 35.7 µg/m^3 within one minute, although it fluctuated around a constant level until the end of sampling duration. Interestingly, there was no other bus (than Bus #232) arriving at or departing from Davis Bay Elementary at the time of measurement.

Discussion

Although the findings suggest that the school students were not exposed to unsafe levels of pollutants, one of the limitations of the study is that both the provincial and national standards are 24-hour averages as opposed to the one-hour averages of the collected data. Despite it being more logical to compare concentration averages over the same duration of time, it was infeasible to acquire $PM_{2.5}$ concentrations over 24 consecutive hours. Yet, since the fluctuations of the $PM_{2.5}$ fall well below the standards, it can be inferred that hypothetically, if the students are to stay there for 24 hours under the same conditions, that 24-hour average would still be below the standards.

With respect to the standards, several factors could explain why they are exceeded during the bus rides, such as the number of students on-board the buses, their movements (such as turning back on their seats) that could re-suspend fine particles, dispersion of pollutants from outside the bus through open doors during idle at the schools or through windows during the bus journey. Previous studies have suggested that self-pollution, a phenomenon whereby the school buses' own exhausts cause heightened in-cabin concentrations, could be one of the contributing factors (Adar et al., 2008).

When comparing the instances when the bus doors were open with the concentration peaks aboard the buses, no clear relationship was found. Because the windows were closed due to the winter climate in January, the increases could be attributed to the students' movements inside the buses, especially important when the buses are fully occupied. However, this could not be quantified given the difficulty in observing the activity of every single student on their trip home from a narrow viewpoint. Moreover, closed windows could worsen the extent of self-pollution from the diesel buses' own exhausts (Adar et al., 2008).

Another factor that could potentially be the source of such misalignment is the lack of airflow within the buses, which could affect the suspension and settlement of fine particles. Reduced air exchange with the surrounding environment could reduce the rate of particulate dispersion inside the buses, thus increasing the time needed for DC1700 to detect the changes in concentration. It may explain the peaks that occurred after a departure from a certain school; however, it is not a conclusive evidence and causality cannot be inferred.

As for outdoor air quality observed at the school stops, the low level of pollutants could be attributed to a mixed layer that is formed because of surface heating (during the day). This layer causes pollutants to be more evenly distributed throughout the atmosphere, rather than leaving a bulk of it on ground-level. However, it would be significantly higher during the night and early morning when a stable layer keeps the pollutants at surface level. Additionally, some Sunshine Coast residents tend to burn woods in the morning, which in aggregate would lead to poorer air quality. Therefore, it is likely that students are exposed to poorer air quality at bus stops in the morning. Further study is required to validate the extent of students' exposure to pollutants in early morning and pollutant sources.

Overall, the average concentrations of $PM_{2.5}$ at the school stops were lower than the allowable values. However, as was mentioned before, this finding is limited by the fact that we could not accurately compare our sampling trip average to the 24-hour average standards. This holds for the air quality aboard buses as well, where the one-hour average concentrations for each bus trip were relatively lower than the standards. These signify that the students are exposed to safe level of pollutants both aboard the school buses and at the school bus stops.

Cost-Benefit Analysis

Methodology

A cost-benefit analysis (CBA) was employed using a discounted cash-flow model to appraise the feasibility of purchasing an electric bus compared to a diesel bus. The electric bus selected for this analysis is the eLion electric bus. The model selected would be the maxed-out version with 5 batteries that can sustain a range of 100 miles and with a 19.2 kW AC charger that has a 6.5-hour charging time.

Though there is an increasing selection of electric school buses ranging from the Starcraft e-Quest XL and SSTe electric Type A school bus, the e-Lion was selected due to the abundance of publicly available information regarding its specifications and the feasibility of implementation since the eLion has already been introduced in school districts in both Quebec and California (Lion Buses, 2017). For simplicity of comparison, the greenhouse gas emissions from the electric bus is assumed to be zero.

Purchasing a diesel or electric bus are the two options that Thirdwave Bus Services must decide between when considered under a scenario where an old diesel bus needs to be replaced. Thus, instead of a fleet-wide comparison, the CBA is framed around a singular bus scenario to determine whether purchasing a single diesel or a single electric bus is more beneficial. Benefits and costs every year are treated as annual cash flows that accrue over the project's duration of 16 years which corresponds to the average lifespan of a diesel bus (Reynolds & Lupacchino, 2016). The annual flows are then summed and discounted to a reference year 0, set at 2016, using a discount rate of 3%.

A discount rate of 3% was used based on a similar research conducted by Noel & McCormack in 2014. Though this is typically lower than the discount rates employed in the private sector, this low value was selected because benefits from swapping to an electric bus accrue in the distant future rather than immediately. For perspective, the Environmental Protection Agency typically uses a discount rate between 2-3% whilst those not dealing with environmental issues use anywhere between 3.5% to 15% (Harrison, 2010).

Three investment decision-making criteria are considered: the present value of aggregate net benefits (ANB), the internal rate of return (IRR), and the discounted payback period as per our community partner's request. The CBA considers the two mutually exclusive projects as a single project that is defined as the difference between the two projects' cash flows (*i.e.,* net benefits from electric bus project "E"– net benefits from diesel bus project "D"). A positive result would mean the net benefits from project E is larger than project D and thus project E should be chosen over project D. A negative result may imply the costs of project E is higher or that project D has more benefits.

Furthermore, to make a distinction between purely financial benefits to the bus firm (private perspective) – and economic benefits to the Sunshine Coast Public (societal perspective), benefits and costs are separated into private and public "cash-flows". Thus, the 2 perspectives considered in this study are:

1. *Private analysis:* the private CBA only considers cash flows that directly impact Thirdwave Bus Service's financial position.
2. *Public analysis*: this perspective consists of all the stakeholders affected by the project. This includes the school district, people of Sunshine Coast, and Thirdwave Bus Services.

The public perspective also considers the private perspective in addition to wider implications that do not directly affect the firm's financial position, such as the cost of environmental damage to the greater Sunshine

Coast community and other externalities. Three externalities are considered as part of the public perspective analysis:

- Social cost of carbon
- Health externalities from vehicles of the same weight class as typical Type C school buses
- Social cost of noise pollution

Thus, the ANB is separated into a private and public component (Campbell & Brown, 2016).

Most of the values used in the CBA are derived from a diversity of sources. Information specific to the diesel bus was primarily obtained directly from Thirdwave Bus Services and most other information was obtained from literature research from websites, articles, reports, and presentations. Several values were estimated based on available information – such as annual fuel cost and annual distance travelled. Assumptions were made for several values whose "true" value, insofar as the literature search permits, cannot be ascertained. This includes the residual value of an electric bus after 16 years and the average rate of maintenance cost rise for diesel buses, assumed at 5%. For a more comprehensive list of assumptions, see Appendix I.

To keep values in the reference year consistent, all inputs variables were standardized to Canadian dollar (CAD) worth in 2016. Values given initially in U.S. Dollars (USD) were first converted to the 2016 equivalent in USD using the consumer price index (CPI), and subsequently converted to CAD based on the average exchange rate in 2016. Values originally in CAD were standardized based on CPI.

Results

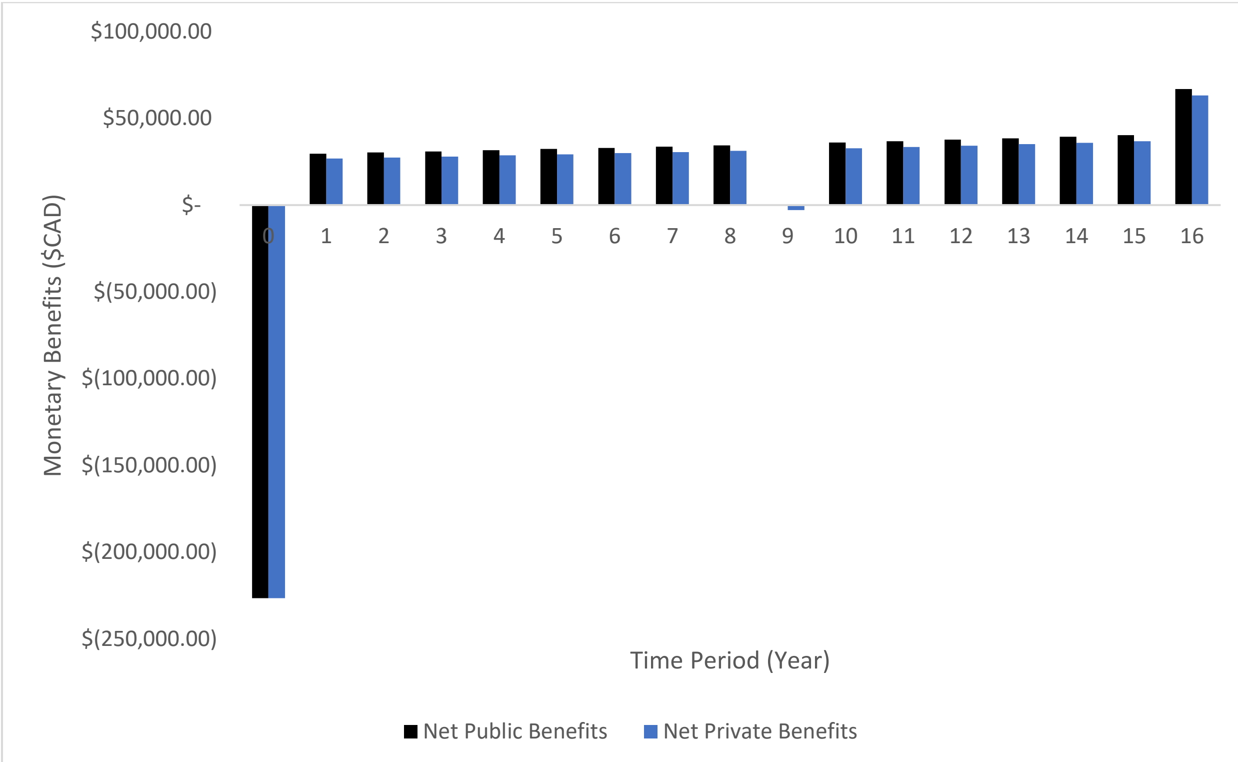

Figure 4:Undiscounted stream of both net private and public benefits (in 2016 Canadian Dollars) that is generated if an electric bus is adopted instead of a diesel bus over a 16-year timeframe corresponding to the average lifespan of diesel and electric buses. Time 0 represents the initial point of purchase and bars for periods 1 to 16 represent the net benefits accrued for that year period.

The largest cost for any of the time periods occurs at the point of purchase from the initial capital cost for acquiring the electric bus. The cost savings for period 0 is negative since the cost of the diesel bus ($100,000) is lower than the current cost of the electric bus ($326,380) even with a subsidy of $5,000 from the provincial government. In year 9, both public and private benefits are close to 0 since the cost of battery replacement offsets the benefits generated by the electric bus. Other than year 0 and 9, both private and public net benefits are positive for every other year, with a notably higher benefit in the last year due to the possibility of selling off the electric bus at its salvage value – assumed at 10% of its initial capital cost.

Interestingly, the difference between private and public net benefit streams every year is almost negligible since they are roughly equal. This is likely due to the externalities being priced rather low relative to the private costs and benefits – the annual carbon savings are between $726.99 and $973.49, and the annual social cost of noise is $665.79, whilst annual fuel costs are approximately $6,600 and annual V2G revenues are above $20,000. The ratio of positive externalities (the health and carbon savings) to private benefits (V2G revenues) is approximately 1:10; for costs, this externality to private cost ratio is approximately 1:7.

Furthermore, without considering the dollar value of carbon savings, the carbon dioxide reductions from a single electric bus – estimated from multiplying the carbon dioxide emission per litre by the annual diesel consumption – would amount to 16,930 tonnes of carbon dioxide.

Investment Decision-making criteria	Private Analysis	Public Analysis
Present Value of Aggregate Net Benefits	$ 157,484.15	$ 197,568.03
Discounted Payback Period (Years)	7.82	9.06
Internal Rate of Return	10.20%	11.84%

Table 3: Summary results of the three investment decision-making criteria separated between the private and public perspectives

From both the private firm and society's perspectives, purchasing the electric bus would generate more cost savings and benefits than purchasing a diesel bus would due to the positive ANB. The discounted payback periods are also below the project's timeframe of 16 years and the internal rate of returns are both above the discount rate of 3%.

Sensitivity analysis

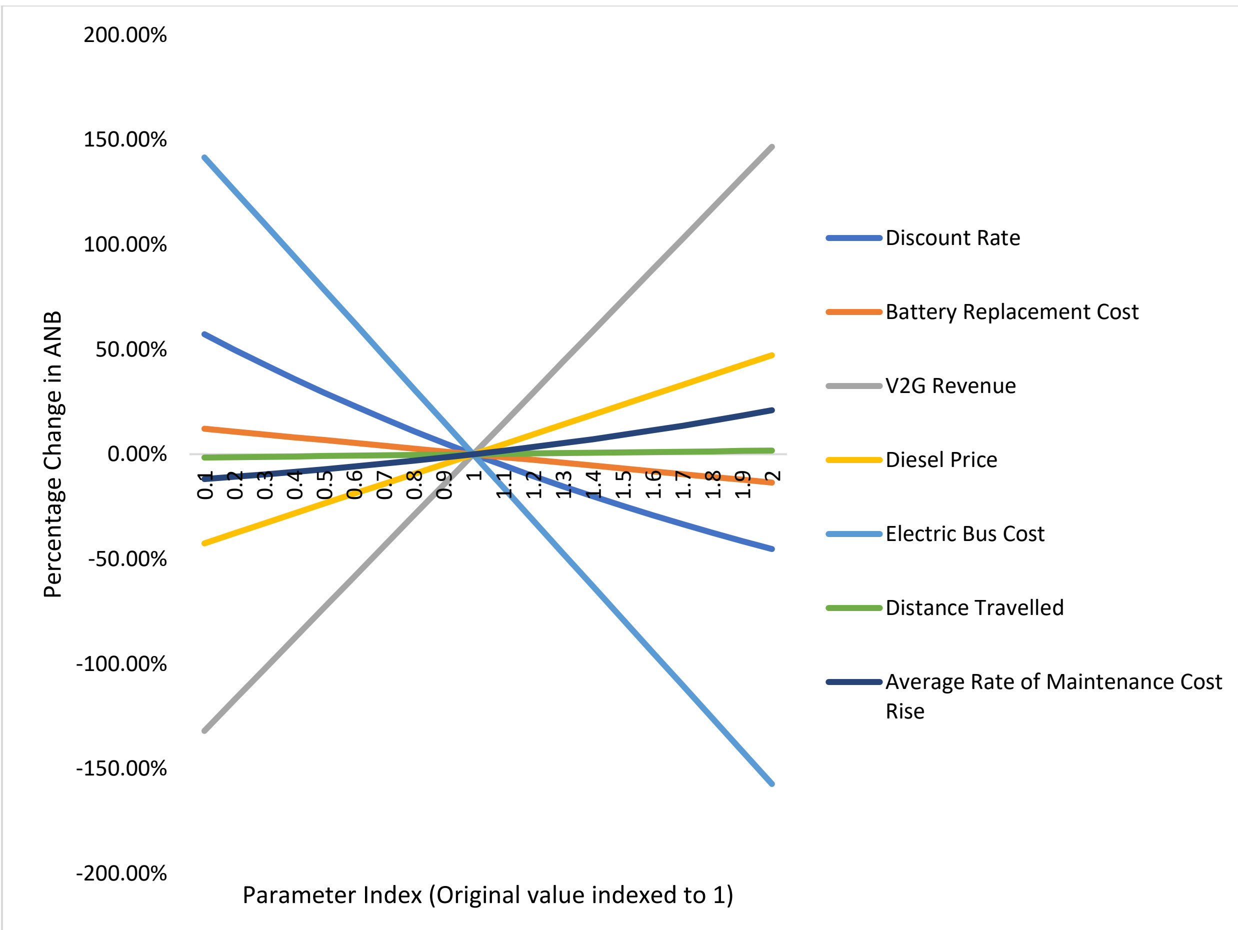

Figure 5: The percentage change on the public ANB because of 10% incremental variations of different parameters from their original value, which is denoted as an index of 1. Every 0.1-unit change in the index denotes a 10% change in the parameter. The gradient of the line is an indication of the sensitivity of the ANB to a change in that parameter; the larger the gradient, the more susceptible the ANB is to changes in that parameter.

The two most sensitive parameters are the electric bus cost and the V2G revenues: a +10% change in the cost of the electric bus would result in a -15.73% reduction in the net benefits whilst a +10% change in V2G revenues would lead to a 14.66% net benefit reduction. These are the only two variables where variation within 10% to 200% of its original value could lead to a swap in the sign of the net benefits. If annual V2G revenues reduce by 70%, the ANB will attain a negative value of -$5,228.14; similarly, if the price of the eLion electric bus increases by 70% - despite how unlikely such a scenario would be – then the public net benefits will become -$19,942.78, instead.

Meanwhile, battery replacement cost, rate of maintenance cost rise, and distance travelled all had negligible effects on the ANB. It is likely that battery replacement has little impact on the ANB despite its expensiveness, which is forecasted to be priced at $34,830 by 2025, since it is only a one-time cost within the project's expected timeframe and is also discounted.

It is also perhaps worth noting that a 10% increase in the diesel price would entail a 4.72% increase for the ANB which indicates the benefits of being less susceptible to fossil fuel volatility, and cost savings accrued from swapping to an electric bus.

Due to the linearity of the variables, the effect on the ANB of incremental 10% variations in the parameters are constant and perhaps also easily understood in the form of a table:

10% Change in Parameter	Percentage Change in PVANB
Discount Rate	-5.27%
Battery Replacement Cost	-1.35%
V2G Revenue	14.66%
Diesel Price	4.72%
Electric Cost	-15.73%
Distance Travelled	0.17%
Average Rate of Maintenance Cost Rise	1.66%

Table 4: Percentage change in the public ANB because of a +10% change in the parameters.

Discussion

Based on the large positive ANB of $197,568.03, an IRR larger than the discount rate of 3%, and a discounted payback period that falls below 16 years, the results suggest that it is more favourable to purchase an electric bus as opposed to a diesel bus when considering replacing an old bus in the existing bus fleet.

Despite the investment criteria being satisfied, a few words of caution regarding the analysis' limitations should be highlighted. Most importantly, it is highly likely that the V2G revenues were overestimated. The V2G variable was assumed at $20,246 based on the calculations conducted by Noel & McCormack for a similar electric bus – the Smith Newton eTrans electric school bus – in their study. Considering that the installation of EV infrastructure is still being discussed in policy in B.C., and the uncertainty of V2G implementation in Vancouver, this has major implications for deciding the appropriateness of the project. Holding everything constant and varying the V2G revenues, the minimum amount of V2G revenues required for the Public ANB to remain positive is approximately $6,000. Considering the sensitivity of the Public ANB to V2G revenues as well, it would be critical to understand the futurity of V2G technology availability. But if V2G were available, the results would suggest a very strong case for switching to electric buses.

It should also be noted that many private costs and benefits were omitted from this study. The firm-level financial information provided was incomprehensive – although information regarding estimated annual fuel costs and diesel bus purchase cost were given, others such as operating costs, taxes, and revenues were not available. Aside from the electric vehicle subsidy, which is worth $5,000 at the point of sale and provided as part of British Columbia's Clean Energy Vehicle Program, which is included in the study, potential tax rebates or other financial incentives that the local government may have enacted are not included. With incomplete information, it is unclear whether the private ANB will remain positive when other potential costs and revenues are not considered.

Additionally, some public benefits and costs that are different between electric and diesel buses are omitted from the study or not captured to their full extent. Switching to electric buses tends to generate stronger community cohesiveness than diesel buses, but this benefit is not captured (Litman, 2017). With respect to the health and noise pollution social costs considered, they are not captured fully – and most relevantly – for the area of Sunshine Coast. Without being able to conduct a location-specific contingent valuation of statistical life and Sunshine Coast's people's willingness to pay for a reduction of noise, the primary limitation of the social costs appraisal is that they are all primarily based on scholarly literature and perhaps not specific to the location and referent group in this study. Indeed, the health externality was based off emissions of the same tonnage as school buses in the United States – not Canada.

Conclusions

The study showed that concentrations of $PM_{2.5}$ are generally higher on a school bus relative to the ambient levels; students are exposed to a poorer air quality when they are aboard the school buses compared to when they are on the school ground. It could be a result of lack of air exchange with the outdoor environment or activity of occupants within the buses.

Nevertheless, the concentrations of $PM_{2.5}$ both on the buses and school bus stops are generally lower than the Air Quality Objective and Canadian Ambient Air Quality Standards. This study shows that the students are exposed to a safe level of $PM_{2.5}$, although it does not consider other harmful pollutants, such as oxides of nitrogen and PM_{10}. Further study is required to investigate the effect of diesel-powered school buses on the concentration of these pollutants.

With respect to our second research objective, both the results of the CBA and the ANOVA suggest that purchasing an electric bus instead of a diesel bus would yield more benefits than costs. All three investment decision-making criteria – the internal rate of return, the ANB, and discounted payback period – point towards purchasing an electric bus instead of a diesel bus as the most favourable investment decision. Without considering monetary costs or benefits, the statistically significant difference in the average $PM_{2.5}$ concentrations between that on the bus and that at the bus stop signifies that, under the assumption that electric buses produce zero emissions and that most of the particulate matter on board the bus is due to its own exhaust, a switch to an electric bus would lower the $PM_{2.5}$ concentrations children would be exposed to when commuting.

It is worth mentioning that, although the CBA showed that the overall favourability of purchasing an electric bus is contingent on the existence of revenues from V2G technology, this analysis will likely prove more useful in the future than today. Perhaps the need of replacing an existing diesel bus is not imminent at present, but when it is in the future, it is likely that electric buses will become the more favourable option. If one must make an intelligent speculation, electric buses would be cheaper and V2G revenues would become higher – or at least, feasibly implemented – in the future. With falling battery costs, bus prices, and V2G feasibility, electric buses may then become the go-to capital replacement choice.

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Appendix I - Cost-Benefit Analysis Assumptions:

1. The study assumes the bus services firm (or school district) is considering the purchase of a new vehicle to replace an existing diesel bus nearing the end of its operational lifetime;
2. There is no ridership optimization and all routes remain the same – with no change from the current route as provided by Thirdwave Bus Services;
3. V2G technology is available;
4. The electric bus considered can complete their morning and afternoon pickup and drop-off sessions across the Sunshine Coast with a single full charge;
5. According to the bus schedule provided, all the buses will be in operation between 7am to 10am and 2pm and 5pm. The rest of the downtime the bus would be charging and providing the owners with V2G revenue;
6. Projection of Diesel Gas prices for the next 15 years was held constant at 1.033 $CAD/L;
7. Reduction in battery cost, in terms of price per kilowatt hour, is linear with respect to time – at 11% per year;
8. Average distance travelled per year was estimated by multiplying average distance travelled per year by the number of bus operational days (in terms of school days).

Appendix II - Annual Electric Cost Calculation

Electric Bus

Time	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Year	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032
Benefits																	
GHG savings	$ -	$ 726.99	$ 726.99	$ 726.99	$ 805.58	$ 805.58	$ 805.58	$ 805.58	$ 805.58	$ 889.54	$ 889.54	$ 889.54	$ 889.54	$ 889.54	$ 889.54	$ 973.49	$ 973.49
Health Savings	$ -	$ 1,666.54	$ 1,693.76	$ 1,721.42	$ 1,749.53	$ 1,778.10	$ 1,807.13	$ 1,836.64	$ 1,866.64	$ 1,897.12	$ 1,928.10	$ 1,959.59	$ 1,991.59	$ 2,024.11	$ 2,057.16	$ 2,090.75	$ 2,124.90
V2G revenue	$ -	$ 20,576.63	$ 20,912.64	$ 21,254.14	$ 21,601.22	$ 21,953.97	$ 22,312.48	$ 22,676.84	$ 23,047.16	$ 23,423.52	$ 23,806.02	$ 24,194.78	$ 24,589.88	$ 24,991.43	$ 25,399.54	$ 25,814.31	$ 26,235.86
Residual Value	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ 33,138.03
Total Private Benefits	$ -	$ 20,576.63	$ 20,912.64	$ 21,254.14	$ 21,601.22	$ 21,953.97	$ 22,312.48	$ 22,676.84	$ 23,047.16	$ 23,423.52	$ 23,806.02	$ 24,194.78	$ 24,589.88	$ 24,991.43	$ 25,399.54	$ 25,814.31	$ 59,373.89
Total Public Benefits	$ -	$ 22,970.16	$ 23,333.39	$ 23,702.55	$ 24,156.34	$ 24,537.65	$ 24,925.20	$ 25,319.07	$ 25,719.38	$ 26,210.17	$ 26,623.66	$ 27,043.90	$ 27,471.00	$ 27,905.07	$ 28,346.24	$ 28,878.56	$ 62,472.27
Discounted Private Benefits	$ -	$ 19,977.31	$ 19,712.17	$ 19,450.55	$ 19,192.41	$ 18,937.69	$ 18,686.35	$ 18,438.35	$ 18,193.64	$ 17,952.18	$ 17,713.92	$ 17,478.82	$ 17,246.84	$ 17,017.95	$ 16,792.09	$ 16,569.23	$ 36,999.84
Discounted Public Benefits	$ -	$ 22,301.12	$ 21,993.96	$ 21,691.19	$ 21,462.59	$ 21,166.40	$ 20,874.46	$ 20,586.72	$ 20,303.11	$ 20,087.91	$ 19,810.50	$ 19,537.09	$ 19,267.60	$ 19,002.00	$ 18,740.20	$ 18,536.05	$ 38,930.65
Costs																	
Purchase Cost	$ 326,380.25	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Annual Fuel Cost	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Annual Maintenance Cost	$ -	$ 2,384.49	$ 2,423.42	$ 2,463.00	$ 2,503.22	$ 2,544.10	$ 2,585.64	$ 2,627.87	$ 2,670.78	$ 2,714.39	$ 2,758.72	$ 2,803.77	$ 2,849.55	$ 2,896.09	$ 2,943.38	$ 2,991.45	$ 3,040.30
Electricity Cost	$ -	$ 2,165.80	$ 2,201.17	$ 2,237.11	$ 2,273.64	$ 2,310.77	$ 2,348.51	$ 2,386.86	$ 2,425.84	$ 2,465.45	$ 2,505.71	$ 2,546.63	$ 2,588.22	$ 2,630.48	$ 2,673.44	$ 2,717.09	$ 2,761.46
Battery Replacement Cost	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ 34,830.36	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Depreciation Cost	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Noise Costs	$ -	$ 665.79	$ 676.66	$ 687.71	$ 698.94	$ 710.35	$ 721.95	$ 733.74	$ 745.72	$ 757.90	$ 770.28	$ 782.86	$ 795.64	$ 808.63	$ 821.84	$ 835.26	$ 848.90
Total Private Costs	$ 326,380.25	$ 4,550.28	$ 4,624.59	$ 4,700.11	$ 4,776.86	$ 4,854.87	$ 4,934.15	$ 5,014.72	$ 5,096.61	$ 40,010.20	$ 5,264.43	$ 5,350.40	$ 5,437.77	$ 5,526.57	$ 5,616.82	$ 5,708.54	$ 5,801.76
Total Public Costs	$ 326,380.25	$ 5,216.07	$ 5,301.25	$ 5,387.82	$ 5,475.80	$ 5,565.22	$ 5,656.10	$ 5,748.46	$ 5,842.34	$ 40,768.10	$ 6,034.71	$ 6,133.25	$ 6,233.41	$ 6,335.20	$ 6,438.65	$ 6,543.80	$ 6,650.66
Discounted Private Costs	$ 326,380.25	$ 4,417.75	$ 4,359.12	$ 4,301.27	$ 4,244.18	$ 4,187.85	$ 4,132.27	$ 4,077.43	$ 4,023.31	$ 30,664.49	$ 3,917.23	$ 3,865.24	$ 3,813.94	$ 3,763.32	$ 3,713.38	$ 3,664.09	$ 3,615.46
Discounted Public Costs	$ 326,380.25	$ 5,064.15	$ 4,996.94	$ 4,930.62	$ 4,865.18	$ 4,800.61	$ 4,736.90	$ 4,674.03	$ 4,612.00	$ 31,245.35	$ 4,490.39	$ 4,430.79	$ 4,371.99	$ 4,313.96	$ 4,256.71	$ 4,200.21	$ 4,144.47

Diesel Bus

Time	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Year	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032
Benefits																	
GHG savings	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Health Savings	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Residual/Resale value	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ 7,566.12
Total	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ 7,566.12
Discounted Flows	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ 4,714.95
Costs																	
Purchase Cost	$ 100,000.00	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Annual Fuel Cost	$ -	$ 6,627.96	$ 6,736.19	$ 6,846.19	$ 6,957.99	$ 7,071.61	$ 7,187.09	$ 7,304.46	$ 7,423.74	$ 7,544.97	$ 7,668.18	$ 7,793.40	$ 7,920.67	$ 8,050.01	$ 8,181.47	$ 8,315.07	$ 8,450.86
Annual Maintenance Cost	$ -	$ 4,200.00	$ 4,410.00	$ 4,630.50	$ 4,862.03	$ 5,105.13	$ 5,360.38	$ 5,628.40	$ 5,909.82	$ 6,205.31	$ 6,515.58	$ 6,841.36	$ 7,183.43	$ 7,542.60	$ 7,919.73	$ 8,315.71	$ 8,731.50
Electricity Cost	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Battery Replacement Cost	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Depreciation Cost	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Noise Costs	$ -	$ 1,102.71	$ 1,120.71	$ 1,139.02	$ 1,157.62	$ 1,176.52	$ 1,195.73	$ 1,215.26	$ 1,235.10	$ 1,255.27	$ 1,275.77	$ 1,296.60	$ 1,317.78	$ 1,339.30	$ 1,361.17	$ 1,383.40	$ 1,405.99
Total Private Costs	$ 100,000.00	$ 10,827.96	$ 11,146.19	$ 11,476.69	$ 11,820.02	$ 12,176.74	$ 12,547.48	$ 12,932.86	$ 13,333.56	$ 13,750.28	$ 14,183.76	$ 14,634.76	$ 15,104.09	$ 15,592.61	$ 16,101.20	$ 16,630.78	$ 17,182.36
Total Public Costs	$ 100,000.00	$ 11,930.66	$ 12,266.90	$ 12,615.71	$ 12,977.63	$ 13,353.26	$ 13,743.21	$ 14,148.12	$ 14,568.67	$ 15,005.56	$ 15,459.53	$ 15,931.36	$ 16,421.87	$ 16,931.91	$ 17,462.36	$ 18,014.18	$ 18,588.34
Discounted Private Costs	$ 100,000.00	$ 10,512.58	$ 10,506.35	$ 10,502.80	$ 10,501.93	$ 10,503.76	$ 10,508.31	$ 10,515.60	$ 10,525.64	$ 10,538.45	$ 10,554.05	$ 10,572.46	$ 10,593.71	$ 10,617.81	$ 10,644.79	$ 10,674.67	$ 10,707.48
Discounted Public Costs	$ 100,000.00	$ 11,583.17	$ 11,562.73	$ 11,545.16	$ 11,530.46	$ 11,518.64	$ 11,509.72	$ 11,503.72	$ 11,500.64	$ 11,500.51	$ 11,503.34	$ 11,509.16	$ 11,517.97	$ 11,529.80	$ 11,544.68	$ 11,562.62	$ 11,583.64

Diesel vs. Electric

Time	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Private Cost Savings	$ (226,380.25)	$ 6,277.67	$ 6,521.60	$ 6,776.58	$ 7,043.15	$ 7,321.87	$ 7,613.33	$ 7,918.14	$ 8,236.95	$ (26,259.92)	$ 8,919.33	$ 9,284.36	$ 9,666.32	$ 10,066.04	$ 10,484.38	$ 10,922.25	$ 11,380.60
Discounted Private Cost Savings	$ (226,380.25)	$ 6,094.83	$ 6,147.23	$ 6,201.53	$ 6,257.75	$ 6,315.91	$ 6,376.04	$ 6,438.17	$ 6,502.32	$ (20,126.04)	$ 6,636.82	$ 6,707.22	$ 6,779.76	$ 6,854.48	$ 6,931.41	$ 7,010.57	$ 7,092.01
Public Cost Savings	$ (226,380.25)	$ 6,714.59	$ 6,965.66	$ 7,227.89	$ 7,501.83	$ 7,788.04	$ 8,087.11	$ 8,399.65	$ 8,726.33	$ (25,762.54)	$ 9,424.82	$ 9,798.11	$ 10,188.46	$ 10,596.71	$ 11,023.71	$ 11,470.38	$ 11,937.68
Discounted Public Cost Savings	$ (226,380.25)	$ 6,519.02	$ 6,565.80	$ 6,614.54	$ 6,665.28	$ 6,718.03	$ 6,772.83	$ 6,829.69	$ 6,888.64	$ (19,744.85)	$ 7,012.95	$ 7,078.36	$ 7,145.98	$ 7,215.84	$ 7,287.97	$ 7,362.40	$ 7,439.17
Net Private Benefits	$ (226,380.25)	$ 26,854.30	$ 27,434.24	$ 28,030.73	$ 28,644.38	$ 29,275.84	$ 29,925.81	$ 30,594.98	$ 31,284.11	$ (2,836.40)	$ 32,725.35	$ 33,479.14	$ 34,256.20	$ 35,057.47	$ 35,883.92	$ 36,736.56	$ 63,188.37
Net Discounted Private Benefits	$ (226,380.25)	$ 26,072.13	$ 25,859.40	$ 25,652.09	$ 25,450.16	$ 25,253.60	$ 25,062.39	$ 24,876.52	$ 24,695.96	$ (2,173.86)	$ 24,350.74	$ 24,186.04	$ 24,026.61	$ 23,872.43	$ 23,723.50	$ 23,579.80	$ 39,376.90
Net Public Benefits	$ (226,380.25)	$ 29,684.75	$ 30,299.05	$ 30,930.44	$ 31,658.17	$ 32,325.69	$ 33,012.31	$ 33,718.73	$ 34,445.71	$ 447.63	$ 36,048.48	$ 36,842.01	$ 37,659.46	$ 38,501.78	$ 39,369.94	$ 40,348.94	$ 66,843.84
Discounted Net Public Benefits	$ (226,380.25)	$ 28,820.15	$ 28,559.76	$ 28,305.74	$ 28,127.87	$ 27,884.43	$ 27,647.29	$ 27,416.41	$ 27,191.76	$ 343.07	$ 26,823.46	$ 26,615.45	$ 26,413.59	$ 26,217.84	$ 26,028.17	$ 25,898.45	$ 41,654.87
Cumulative Discounted Private Cost Savings	$ (226,380.25)	$ (220,285.42)	$ (214,138.19)	$ (207,936.66)	$ (201,678.91)	$ (195,363.00)	$ (188,986.96)	$ (182,548.79)	$ (176,046.47)	$ (196,172.50)	$ (189,535.69)	$ (182,828.47)	$ (176,048.70)	$ (169,194.22)	$ (162,262.81)	$ (155,252.23)	$ (148,160.22)
Cumulative Discounted Public Cost Savings	$ (226,380.25)	$ (219,861.23)	$ (213,295.43)	$ (206,680.89)	$ (200,015.61)	$ (193,297.58)	$ (186,524.75)	$ (179,695.06)	$ (172,806.42)	$ (192,551.27)	$ (185,538.31)	$ (178,459.95)	$ (171,313.97)	$ (164,098.12)	$ (156,810.15)	$ (149,447.75)	$ (142,008.58)
Cumulative Net Private Benefits	$ (226,380.25)	$ (199,525.95)	$ (172,091.71)	$ (144,060.99)	$ (115,416.61)	$ (86,140.77)	$ (56,214.96)	$ (25,619.98)	$ 5,664.13	$ 2,827.73	$ 35,553.08	$ 69,032.22	$ 103,288.42	$ 138,345.89	$ 174,229.81	$ 210,966.36	$ 274,154.73
Cumulative Net Discounted Private Benefits	$ (226,380.25)	$ (200,308.12)	$ (174,448.72)	$ (148,796.63)	$ (123,346.47)	$ (98,092.87)	$ (73,030.48)	$ (48,153.96)	$ (23,458.00)	$ (25,631.86)	$ (1,281.13)	$ 22,904.92	$ 46,931.52	$ 70,803.96	$ 94,527.45	$ 118,107.25	$ 157,484.15
Cumulative Net Public Benefits	$ (226,380.25)	$ (196,695.50)	$ (166,396.45)	$ (135,466.01)	$ (103,807.85)	$ (71,482.15)	$ (38,469.85)	$ (4,751.12)	$ 29,694.58	$ 30,142.21	$ 66,190.69	$ 103,032.70	$ 140,692.16	$ 179,193.94	$ 218,563.88	$ 258,912.82	$ 325,756.66
Cumulative Discounted Net Public Benefits	$ (226,380.25)	$ (197,560.10)	$ (169,000.35)	$ (140,694.61)	$ (112,566.74)	$ (84,682.31)	$ (57,035.03)	$ (29,618.62)	$ (2,426.86)	$ (2,083.79)	$ 24,739.66	$ 51,355.11	$ 77,768.70	$ 103,986.54	$ 130,014.71	$ 155,913.16	$ 197,568.03

Appendix III - Sensitivity Analysis Results

NPV From Index	Discount Rate	Battery Replacement Cost	V2G Revenue	Diesel Price	Electric Cost	Distance Travelled	Average Rate of Maintenance Cost Rise
0.1	$ 310,661.21	$ 221,593.14	$ (63,169.90)	$ 113,581.50	$ 477,224.78	$ 194,467.42	$ 174,176.61
0.2	$ 296,132.50	$ 218,923.68	$ (34,199.02)	$ 122,913.33	$ 446,151.81	$ 194,811.94	$ 176,302.15
0.3	$ 282,145.75	$ 216,254.23	$ (5,228.14)	$ 132,245.17	$ 415,078.84	$ 195,156.45	$ 178,532.24
0.4	$ 268,677.38	$ 213,584.77	$ 23,742.75	$ 141,577.01	$ 384,005.87	$ 195,500.96	$ 180,872.36
0.5	$ 255,704.92	$ 210,915.31	$ 52,713.63	$ 150,908.84	$ 352,932.89	$ 195,845.47	$ 183,328.27
0.6	$ 243,207.00	$ 208,245.86	$ 81,684.51	$ 160,240.68	$ 321,859.92	$ 196,189.98	$ 185,906.02
0.7	$ 231,163.29	$ 205,576.40	$ 110,655.39	$ 169,572.52	$ 290,786.95	$ 196,534.49	$ 188,612.00
0.8	$ 219,554.38	$ 202,906.94	$ 139,626.27	$ 178,904.35	$ 259,713.97	$ 196,879.01	$ 191,452.90
0.9	$ 208,361.83	$ 200,237.49	$ 168,597.15	$ 188,236.19	$ 228,641.00	$ 197,223.52	$ 194,435.77
1	$ 197,568.03	$ 197,568.03	$ 197,568.03	$ 197,568.03	$ 197,568.03	$ 197,568.03	$ 197,568.03
1.1	$ 187,156.22	$ 194,898.57	$ 226,538.91	$ 206,899.87	$ 166,495.06	$ 197,912.54	$ 200,857.47
1.2	$ 177,110.43	$ 192,229.12	$ 255,509.79	$ 216,231.70	$ 135,422.08	$ 198,257.05	$ 204,312.28
1.3	$ 167,415.40	$ 189,559.66	$ 284,480.67	$ 225,563.54	$ 104,349.11	$ 198,601.56	$ 207,941.09
1.4	$ 158,056.63	$ 186,890.20	$ 313,451.55	$ 234,895.38	$ 73,276.14	$ 198,946.08	$ 211,752.94
1.5	$ 149,020.25	$ 184,220.74	$ 342,422.43	$ 244,227.21	$ 42,203.16	$ 199,290.59	$ 215,757.36
1.6	$ 140,293.04	$ 181,551.29	$ 371,393.31	$ 253,559.05	$ 11,130.19	$ 199,635.10	$ 219,964.34
1.7	$ 131,862.39	$ 178,881.83	$ 400,364.19	$ 262,890.89	$ (19,942.78)	$ 199,979.61	$ 224,384.39
1.8	$ 123,716.26	$ 176,212.37	$ 429,335.07	$ 272,222.72	$ (51,015.75)	$ 200,324.12	$ 229,028.56
1.9	$ 115,843.16	$ 173,542.92	$ 458,305.95	$ 281,554.56	$ (82,088.73)	$ 200,668.63	$ 233,908.45
2	$ 108,232.13	$ 170,873.46	$ 487,276.84	$ 290,886.40	$ (113,161.70)	$ 201,013.15	$ 239,036.24

NPV from Index	Discount Rate	Battery Replacement Cost	V2G Revenue	Diesel Price	Electric Cost	Distance Travelled	Average Rate of Maintenance Cost Rise
0.1	57.24%	12.16%	-131.97%	-42.51%	141.55%	-1.57%	-11.84%
0.2	49.89%	10.81%	-117.31%	-37.79%	125.82%	-1.40%	-10.76%
0.3	42.81%	9.46%	-102.65%	-33.06%	110.09%	-1.22%	-9.64%
0.4	35.99%	8.11%	-87.98%	-28.34%	94.37%	-1.05%	-8.45%
0.5	29.43%	6.76%	-73.32%	-23.62%	78.64%	-0.87%	-7.21%
0.6	23.10%	5.40%	-58.65%	-18.89%	62.91%	-0.70%	-5.90%
0.7	17.00%	4.05%	-43.99%	-14.17%	47.18%	-0.52%	-4.53%
0.8	11.13%	2.70%	-29.33%	-9.45%	31.46%	-0.35%	-3.10%
0.9	5.46%	1.35%	-14.66%	-4.72%	15.73%	-0.17%	-1.59%
1	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
1.1	-5.27%	-1.35%	14.66%	4.72%	-15.73%	0.17%	1.66%
1.2	-10.35%	-2.70%	29.33%	9.45%	-31.46%	0.35%	3.41%
1.3	-15.26%	-4.05%	43.99%	14.17%	-47.18%	0.52%	5.25%
1.4	-20.00%	-5.40%	58.65%	18.89%	-62.91%	0.70%	7.18%
1.5	-24.57%	-6.76%	73.32%	23.62%	-78.64%	0.87%	9.21%
1.6	-28.99%	-8.11%	87.98%	28.34%	-94.37%	1.05%	11.34%
1.7	-33.26%	-9.46%	102.65%	33.06%	-110.09%	1.22%	13.57%
1.8	-37.38%	-10.81%	117.31%	37.79%	-125.82%	1.40%	15.92%
1.9	-41.37%	-12.16%	131.97%	42.51%	-141.55%	1.57%	18.39%
2	-45.22%	-13.51%	146.64%	47.23%	-157.28%	1.74%	20.99%

Appendix IV - List of Parameters and Variables

Variable	Standardized value	Unit
Discount Rate	3	*%*
Bus operational days	179	*days*
Effective Diesel and Electric Seating Capacity	47	
Average distance travelled per day	120	*km*
Annual Distance Travelled	21480	*km*
BC Electric Vehicle subsidy	5000	*$CAD*
Average Diesel Gas Cost	1.032989016	*$CAD/L*
Rate of reduction in Battery Cost	11	*%*
Average Rate of Inflation	1.633	*%*
Average Rate of maintenance cost rise	5	*%*
Depreciation Rate of buses	0.149	*Rate*
Potential Annual V2G Revenue	20246.00775	*$CAD*

Conversion Parameters

2015 USD/CAD Exchange Rate	1.279163	
2016 USD/CAD Exchange Rate	1.325521	*1 USD to 1 CAD*
Miles to km	1.609934	*km/mile*
Gallons to Litre	3.78541	*L/G*
2007-2016 USD CPI Currency Conversion	1.157541646	
2012-2016 CAD CPI Currency Conversion	1.05505341	

Social Costs

2016 Social Cost of Carbon	0.042940674	*$2016CAD/kgCO2*
2020 Social Cost of Carbon	0.047582909	*$2016CAD/kgCO2*
2025 Social Cost of Carbon	0.05254166	*$2016CAD/kgCO2*
2030 Social Cost of Carbon	0.057500411	*$2016CAD/kgCO2*
Social Cost of Noise (Electric)	0.030497563	*$2016CAD/km*
Social Cost of Noise (Diesel bus)	0.050511589	*$2016CAD/km*
Social Cost of Health Damages	0.076339214	*$2016CAD/km*

Diesel Bus Information	Standardized value	Unit
Diesel Bus Purchase Cost	100000	*$CAD*
Diesel Annual Maintenance Cost	4000	*$CAD*
Diesel Bus Life Expectancy	10	*Years*
Diesel Fuel Economy	3.402398155	*kmPL*
Emission per Litre	2.6817	*kgCO2/L*
Annual Diesel Consumption	6313.194112	*L*
Annual Fuel Cost	6521.460172	*$CAD*
Residual Value after 10 years	19920.28744	*$CAD*
Residual Value after 16 years	7566.115407	*$CAD*

Energy Calculation

Operational hours per day	1.64	*hours*
Annual average daily rate of electricity consumption	68.17428389	*kW*
Basic Charge	0.2347	*$CAD*
Annual Basic Charge	42.0113	*$CAD*
Annual Demand Charge	189.7569039	*$CAD*
Annual Energy Charge	1899.232156	*$CAD*
Total Energy Charge	2131.00036	*$CAD*

eLion Electric Bus Information

Electric Bus Purchase Cost	331380.25	*$CAD*
Electric Annual Maintenance Cost	2346.17217	*$CAD*
Electric Bus Life Expectancy	15	*Years*
Electricy consumption per km	0.931715213	*kwh/km*
Annual Electricity Demand	20013.24278	*kwh*
4 Battery Range	120.74505	*km*
5 Battery Range	160.9934	*km*
Battery Life Expectancy	9	*Years*
Price per kwh in Battery	994.14075	*$/kwh*
Battery Capacity	100	*kwh*
Battery Replacement Cost after 9 years	34830.35779	*$CAD*
Residual Value after Lifetime	33138.025	

Appendix VI - Variable and parameter sources

Variable	Source	eLion Electric Bus Information	Source
Discount Rate	Noel, L., & McCormack, R. (2014). A Cost Benefit Analysis of a V2G-Capable Electric School Bus Compared to a Traditional Diesel School Bus. *Applied Energy* , 246-265.	Electric Bus Purchase Cost	http://stnonline.com/news/latest-news/item/6225-all-electric-elion-getting-ready-to-roar-before-2015-release
Bus operational days	Third Wave Bus Services	Electric Annual Maintenance Cost	Noel, L., & McCormack, R. (2014). A Cost Benefit Analysis of a V2G-Capable Electric School Bus Compared to a Traditional Diesel School Bus. *Applied Energy* , 246-265.
Effective Diesel and Electric Seating Capacity	Third Wave Bus Services	Electric Bus Life Expectancy	https://www.arb.ca.gov/msprog/truckstop/pdfs/electricschoolbus.pdf
Average distance travelled per day	Third Wave Bus Services	Electricy consumption per km	https://www.arb.ca.gov/msprog/truckstop/pdfs/electricschoolbus.pdf
Annual Distance Travelled	ESTIMATED	Annual Electricity Demand	ESTIMATED
BC Electric Vehicle subsidy	"New incentive to make clean energy vehicles more affordable" News Release	4 Battery Range	http://www.lionbuses.com/en/lion-store/
Average Diesel Gas Cost	https://www.arb.ca.gov/msprog/truckstop/pdfs/electricschoolbus.pdf	5 Battery Range	http://www.lionbuses.com/en/lion-store/
Rate of reduction in Battery Cost	https://www.arb.ca.gov/msprog/truckstop/pdfs/electricschoolbus.pdf	Battery Life Expectancy	Noel, L., & McCormack, R. (2014). A Cost Benefit Analysis of a V2G-Capable Electric School Bus Compared to a Traditional Diesel School Bus. *Applied Energy* , 246-265.
Average Rate of Inflation	http://www.inflation.eu/inflation-rates/canada/historic-inflation/cpi-inflation-canada.aspx	Price per kwh in Battery	https://www.arb.ca.gov/msprog/bus/battery_cost.pdf
Average Rate of maintenance cost rise	ASSUMED	Battery Capacity	http://www.lionbuses.com/en/lion-store/
Depreciation Rate of buses	http://www.statcan.gc.ca/pub/15-206-x/2015039/t/tblc14-eng.htm	Battery Replacement Cost after 9 years	ESTIMATED
Potential Annual V2G Revenue	Noel, L., & McCormack, R. (2014). A Cost Benefit Analysis of a V2G-Capable Electric School Bus Compared to a Traditional Diesel School Bus. *Applied Energy* , 246-265.	Residual Value after Lifetime	Assumed at 10% of initial cost
		BC Hydro Business Electricity Rates	https://www.bchydro.com/accounts-billing/rates-energy-use/electricity-rates/business-rates.html

Conversion Parameters	Source
2015 USD/CAD Exchange Rate	http://www.canadianforex.ca/forex-tools/historical-rate-tools/yearly-average-rates
2016 USD/CAD Exchange Rate	http://www.canadianforex.ca/forex-tools/historical-rate-tools/yearly-average-rates
2007-2016 USD CPI Currency Conversion	http://www.usinflationcalculator.com/inflation/consumer-price-index-and-annual-percent-changes-from-1913-to-2008/
2012-2016 CAD CPI Currency Conversion	http://www.statcan.gc.ca/tables-tableaux/sum-som/l01/cst01/econ46a-eng.htm
Social Costs	
2016 Social Cost of Carbon	http://ec.gc.ca/cc/default.asp?lang=En&n=BE705779-1
2020 Social Cost of Carbon	http://ec.gc.ca/cc/default.asp?lang=En&n=BE705779-1
2025 Social Cost of Carbon	http://ec.gc.ca/cc/default.asp?lang=En&n=BE705779-1
2030 Social Cost of Carbon	http://ec.gc.ca/cc/default.asp?lang=En&n=BE705779-1
Social Cost of Noise (Electric)	Victoria Transport Policy Institute
Social Cost of Noise (Diesel bus)	Victoria Transport Policy Institute
Social Cost of Health Damages	https://www.nap.edu/read/12794/chapter/5#179

Diesel Bus Information	Source
Diesel Bus Purchase Cost	Third Wave Bus Services
Diesel Annual Maintenance Cost	Third Wave Bus Services
Diesel Bus Life Expectancy	http://ntl.bts.gov/lib/44000/44200/44244/Bus_Lifecycle_Cost_Model_User_s_Guide.pdf
Diesel Fuel Economy	Third Wave Bus Services
Emission per Litre	http://www.eia.gov/tools/faqs/faq.cfm?id=307&t=11
Annual Diesel Consumption	ESTIMATED
Annual Fuel Cost	ESTIMATED
Residual Value after 10 years	ESTIMATED
Residual Value after 16 years	ESTIMATED

Appendix VII - Diesel Bus Depreciation Calculation using Double Declining Balance Method

Year	Depreciation Rate	Book Value	Annual Depreciation Charge	Accumulated Depreciation
1	0.149	$ 100,000.00	$ 14,900.00	$ 14,900.00
2	0.149	$ 85,100.00	$ 12,679.90	$ 27,579.90
3	0.149	$ 72,420.10	$ 10,790.59	$ 38,370.49
4	0.149	$ 61,629.51	$ 9,182.80	$ 47,553.29
5	0.149	$ 52,446.71	$ 7,814.56	$ 55,367.85
6	0.149	$ 44,632.15	$ 6,650.19	$ 62,018.04
7	0.149	$ 37,981.96	$ 5,659.31	$ 67,677.35
8	0.149	$ 32,322.65	$ 4,816.07	$ 72,493.43
9	0.149	$ 27,506.57	$ 4,098.48	$ 76,591.91
10	0.149	$ 23,408.09	$ 3,487.81	$ 80,079.71
11	0.149	$ 19,920.29	$ 2,968.12	$ 83,047.84
12	0.149	$ 16,952.16	$ 2,525.87	$ 85,573.71
13	0.149	$ 14,426.29	$ 2,149.52	$ 87,723.23
14	0.149	$ 12,276.77	$ 1,829.24	$ 89,552.46
15	0.149	$ 10,447.54	$ 1,556.68	$ 91,109.15
16	0.149	$ 8,890.85	$ 1,324.74	$ 92,433.88

Appendix VI - Equations

a. Private Cost Savings for year *i* ($\boldsymbol{S^i_{d,priv}}$)

$$S^i_{d,priv} = C^i_{d,priv} - C^i_{el,priv}$$

$C^i_{d,priv}$ = *Annual private costs for a diesel bus*

$C^i_{el,priv}$ = *Annual private costs for an electric bus*

b. Public Cost Savings for year *i* ($\boldsymbol{S^i_{d,pub}}$)

$$S^i_{d,pub} = C^i_{d,pub} - C^i_{el,pub}$$

$C^i_{d,pub}$ = *Annual public costs for a diesel bus*

$C^i_{el,pub}$ = *Annual public costs for an electric bus*

c. Net Private Benefits for year *i* ($\boldsymbol{NB^i_{priv}}$)

$$NB^i_{priv} = (C^i_{d,priv} - C^i_{el,priv}) + (B^i_{el,priv} - B^i_{d,priv})$$

$B^i_{el,priv}$ =*Annual private benefits for an electric bus*

$B^i_{d,priv}$ = *Annual private benefits for a diesel bus*

d. Net Public Benefits for year *i* ($\boldsymbol{NB^i_{pub}}$)

$$NB^i_{pub} = (C^i_{d,pub} - C^i_{el,pub}) + (B^i_{el,pub} - B^i_{d,pub})$$

$B^i_{el,pub}$ = *Annual public benefits for an electric bus*

$B^i_{d,pub}$ = *Annual public benefits for a diesel bus*

e. Present Value of Aggregate Net Private Benefits of the Project

$$ANB_{priv} = \sum_{i=0}^{16} \frac{NB^i_{priv}}{(1+r)^i}$$

f. Present Value of Aggregate Net Public Benefits of the Project

$$ANB_{pub} = \sum_{i=0}^{16} \frac{NB^i_{pub}}{(1+r)^i}$$

Appendix VII - ANOVA results

ANOVA - All Days

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Column 1	323	3497.4835	10.8281223	202.278117
Column 2	367	2443.54327	6.65815606	43.4433179

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	2987.33945	1	2987.33945	25.3633588	6.0728E-07	3.85501034
Within Groups	81033.8079	688	117.781698			
Total	84021.1474	689				

Appendix VIII – Map of Schools Sampled (Bus Stops)