MEASUREMENT AND VERIFICATION OF A LOCAL GOVERNMENT GREENHOUSE GAS EMISSIONS REDUCTION PROJECT

PV4EV

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Executive Summary

Several technological developments and scientific findings have led to the discovery that anthropogenic activity is influencing the Earth's natural rate of climate change. Anthropogenic activities result in the emissions of four long-lived chemical compounds that comprise GHGs, carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), and halocarbons.

This project investigated the potential of using photovoltaics to charge electric vehicles (PV4EV), to offset the City of Colwood's corporate greenhouse gas (GHG) emissions. The purpose of this project was to determine the potential GHG reductions that could be achieved in one year through the implementation of ten PV4EV systems in Colwood, BC. The answer to this question was determined, along with others, such as the possible emission reductions when PV4EV is implemented on various scales, the state of the current electricity supply and future demand in Colwood and BC, and finally, how PV4EV could be used to mitigate growing demand. This project also compared the direct and indirect GHG emissions associated with the production of solar panels to GHG emissions produced from internal combustion engine (ICE) vehicles.

Literature reviews, interviews, and a short questionnaire/survey distributed to local electric vehicle users were used to obtain data and information. Qualitative information was also obtained through the interview process that was undertaken to determine perceived barriers and advantages to utilizing PV4EV. By interviewing two users of PV4EVand 13 other EV users, and analyzing our research findings, it has been estimated that for every ten PV4EV installations within the City of Colwood, 35.14 to 35.38 tonnes CO2e emissions per year could be avoided. The implementation of only 60 PV4EV could offset the entire 2012 corporate carbon emissions in the City of Colwood. Current research on the existing electrical generation methods in BC such as hydroelectric generation, natural gas and biofuels, show that there are significant environmental, social and economic impacts associated with these energy sources. In conclusion, this research provides a clear description of the role that photovoltaics (PV) and electric vehicles (EV) may play in mitigating future GHG emissions within the transportation sector.

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Glossary of Terms

BC Climate Action Charter: Agreement signed voluntarily by local BC governments committing to become carbon neutral, measure and report on community GHG emissions, and create compact, complete, and energy-efficient communities.

Becoming Carbon Neutral: Framework created by the Green Communities Committee for local municipalities to utilize in order to meet their BC Climate Action Charter goals and achieve carbon neutrality.

Carbon Dioxide Equivalent (CO_2e): Expression of any greenhouse gas in terms of tonnes of CO_2e.

Carbon Offset: High-quality emission reduction projects, measured in tonnes of carbon dioxide equivalents (CO_2e), generated through projects that avoid or sequester GHGs. Can be purchased to offset the remainder of corporate GHG emissions in order to achieve carbon neutrality.

Climate Action Revenue Incentive Program (CARIP): A provincial government conditional grant program that refunds carbon tax to municipalities who have signed the BC Climate Action Charter.

Climate Change: A significant and persistent alteration of statistical weather pattern distribution over a long period of time.

Community Energy and Emissions Inventory (CEEI): Estimates of the energy use and greenhouse gas emissions within a community over one year.

Electric Vehicle (EV): An automobile that is powered by electricity, and does not contain an internal combustion engine.

Green Communities Committee (GCC): Created through a partnership between the BC Government and the Union of BC Municipalities. Developed the Becoming Carbon Neutral framework for local governments to use to reach their BC Climate Action Charter commitments.

Greenhouse Gas (GHG) Emissions: Gases emitted to the atmosphere that absorb and reflect the sun's radiation. Includes carbon dioxide, methane, nitrous oxide, hydrofluorocarbons, perfluorocarbons, and sulfur hexafluoride.

Greater Victoria Area (GVA): The Greater Victoria Area in a sub-region of the Capital Regional District (CRD), and in this study is considered to include the west shore communities (Langford, Colwood, View Royal), Victoria proper, Esquimalt, and Saanich.

Internal Combustion Engine Vehicle (ICE): Any automobile equipped with an engine powered by the combustion fossil fuels.

Low Emission Vehicle (LEV): An automobile, which emits little or no GHGs compared to conventional internal combustion vehicles, including hybrid-electric, full electric, and high-efficiency internal combustion engines.

Pacific Carbon Trust (PCT): Supplies local governments with the ability to purchase regulated carbon offsets under Option 3 of the Becoming Carbon Neutral framework.

Photovoltaic (PV): Method of generating electricity through conversion of solar radiation into direct current electricity.

PV4EV: The concept of using photovoltaic technology to generate electricity from solar energy to offset the energy used by an electric vehicle.

1.0 Introduction

To measure and verify the GHG emissions reductions achieved by a local government project, several areas of focus were identified and analyzed. These topics include photovoltaic technology, EVs, industry trends, climate change, project sponsor, government carbon neutrality programs and legislature, offset purchasing, current and future electricity demand, and impacts of hydroelectricity. Research also included community outreach, to gain insight into local EV use.

1.1 Background Information

To understand the greenhouse gas emission reductions possible from the installation of PV4EV systems, several aspects, including the impacts of on-grid electricity generation, manufacturing of equipment, and life expectancy of the technology, have been assessed. The following sections provide a background into the history, application, and inner workings of electric vehicles and solar photovoltaics, as well as the implications of their production and current trends in the industry.

1.1.1 Photovoltaic Electricity and Electric Vehicles

Photovoltaic (PV) systems are used to convert solar energy (sunlight) into electricity (Canada Mortgage and Housing Corporation, 2013). PVs consist of interconnected solar cells that form a module when grouped together (Canada Mortgage and Housing Corporation, 2013). These modules are linked to form a panel and multiple panels can be joined to create an array (Canada Mortgage and Housing Corporation, 2013). A typical household will have solar panels installed on their roof, and these will be configured so that the panels receive the maximum sunlight exposure possible. In order for PV systems to create electricity, an array is attached to an inverter, which is able to convert direct current (DC) generated by alternating current (AC) electricity (Canada Mortgage and Housing Corporation, 2013). AC current can be linked to a home's electrical panel or utility meter (Canada Mortgage and Housing Corporation, 2013). The electricity is either consumed by off-grid or grid-connected applications. Off-grid setups are mainly used where electricity is not available, and can be useful for telecommunication, transport route signalling, remote homes, navigational aids, and these remote sensing and monitoring (Canada Mortgage and Housing Corporation, 2013). Most off-grid systems require a battery to store electricity. Grid-connected systems are powered by PV and connected to the utility grid.

Many households are implementing these systems as an alternative electricity source rather than using the common electricity provider.

A PV system for electricity generation can be installed anywhere there is sunlight. Sourcing energy from the sun is a sustainable way to produce electricity without releasing on-site emissions or pollution (Canada Mortgage and Housing Corporation, 2013). PV systems have no moving parts, require little to no maintenance, and can have a lifespan of decades (US Department of Energy, 2008). The cost of PV panels is offset by using less electricity from the utility company and through lower electricity bills (US Department of Energy, 2008). Reduced dependency on utility providers means homeowners will worry less about future energy price increases, energy availability, and energy consumption that produces GHG emissions (US Department of Energy, 2008).

PV electricity can also be used to power electric vehicles (PV4EV). EVs do not use conventional fuels such as gasoline or diesel (Natural Resources Canada, 2010a). Instead, they have a battery-powered electric motor (Natural Resources Canada, 2010a). These batteries can store a certain amount of electricity and must be recharged by plugging in to a power source. Most EVs can be recharged from a standard 240-volt, 40-amp electrical outlet, and some can be recharged from a 110-volt outlet (Natural Resources Canada, 2010 b). On the 240-volt plug, a full charge costs about $2.40, given an average electricity price of 8 cents per kWh (Natural Resources Canada, 2010 b). An EV can drive as long as the battery has sufficient charge.

EVs are commonly categorized as zero-emission vehicles because they do not emit exhaust or emissions (US Department of Energy, 2013a). The source of electricity must be considered when comparing conventional combustion engine vehicles to EVs, as EVs indirectly reduce air pollution, fossil fuel dependence, and GHG emissions that contribute to climate change (BC Ministry of Energy, 2013). Electricity used to power an EV can be sourced more locally, and in the case of PV4EV, electricity from the photovoltaic system is used to charge a personal EV, eliminating large-scale distribution utilities (Natural Resources Canada, 2010b). EVs are more efficient at converting energy to motion than gas combustion vehicles, as they are around 62% efficient, while gas vehicles are about 21% efficient (US Department of Energy, 2013b). Additional advantages of EVs include quiet motors, smooth operation, strong acceleration, and minimal maintenance (US Department of Energy, 2013b).

The most significant negative aspect of an EV is its battery. EVs have a shorter driving range than gas powered vehicles. According to the US Department of Energy (2013a), typical EVs have a range of 100 miles (160.9 km) on a fully charged battery, which is less than a conventional vehicle's range on one tank of gas. One argument against this as a negative factor is that a vehicle with a daily 100-mile range would be adequate for about 90% of household vehicle trips (US Department of Energy, 2013a). The driving range of EVs depends on their battery type. Conventional lead-acid batteries have a range of 50-100 km, whereas nickel metal-hydride and lithium ion batteries have driving ranges of about 200 kilometres or more (Natural Resources Canada, 2010b). The range is limited by the battery size and need for frequent recharging. On average, an EV requires 4-8 h to recharge the vehicle's batteries (US Department of Energy, 2013b). The batteries are also quite bulky, heavy, and expensive to purchase.

1.1.2 Trends in the Industry

As human populations continue to rise, electricity usage also increases. BC Hydro, the province's electricity provider, must maintain this service by increasing electricity costs to balance the demand and maintain energy security. As homeowners try to find cheaper sources of electricity, and become more concerned about the environment, sustainability, and climate change, more residential PV systems may be installed to provide electricity for home usage and to power EVs. Solar energy is a constant energy source provided free by the sun. After the initial cost to install a PV system, there is minimal maintenance needed, and there is no cost to produce electricity from the solar panels (US Department of Energy, 2008).

Technology is rapidly changing all the time. Prices to produce both PV cells and EVs are decreasing as better technology is developed. More models are being released, and EV standards are improving significantly, an example being the Tesla Model S, which was launched in 2012 (Edelstein, 2013). The Tesla is the fastest EV; it has the longest range, and is categorized in the luxury vehicle group (Edelstein, 2013). EV hype is creating competition in the EV manufacturing industry. The more affordable EV group is slowly becoming a more viable vehicle option for the average buyer, and a common EV purchase is the Nissan Leaf (Edelstein, 2013).

EV sales are not expected to increase exponentially, and this may be because of many factors. EV production is conservative; producers of EVs are not participating in large-scale production and there are a limited number of dealers who carry EVs on their sales lots (Edelstein, 2013). Car companies, such as Toyota and Fiat-Chrysler, are mainly producing EVs to comply with emission and energy regulations; they are not producing the vehicles for the buyers, and the EVs produced are not selling that well (Edelstein, 2013). Cost is a major factor deterring buyers from purchasing an EV. EVs do not seem very well accepted in the current market; they may be perceived as too expensive and too inconvenient to overcome the stigma of the electric car.

In order to reduce BC’s GHG emissions, a program called the Clean Energy Vehicles (CEV) for BC has been developed and implemented. This program includes rebates for clean energy vehicles and residential charging points. It provides incentives to BC residents to encourage the purchase and use of clean energy vehicles in the province (New Car Dealers Association of BC, 2013). The program was created and implemented by the BC Ministry of Environment, LiveSmart BC, and the New Car Dealers Association of BC (New Car Dealers Association of BC, 2013). The CEV for BC had $2.5 million of unused funds from 2012, so the program has been extended into 2013-14 until available funding is used up (Government of BC, 2013). As of June 18, 2013, the CEV for BC real-time tracker for available funding shows an available $1.91 million and $390,000 funds distributed (New Car Dealers Association of BC, 2013 b). The Clean Energy Vehicles for British Columbia Point of Sale Incentive Program rebates BC residents up to $5000 off of the pre-tax price of a new vehicle bought or leased from a new car dealership in BC (New Car Dealers Association of BC, 2013). Only light industrial use vehicles powered by natural gas, hydrogen or electricity as the primary fuel source, qualify and there are various other conditions of participating in the program (New Car Dealers Association of BC, 2013). In addition to the vehicle rebate, there is another incentive program for BC residents called the LiveSmart BC Residential Charging Point Rebate Program, which can be valued up to $500 for BC residents installing residential electric vehicle charging stations for their EVs (Government of BC, 2013). As of March 31, 2013, the CEV for BC program funding has been used as a part of the rebates toward 431 clean energy vehicles, 111 residential charging points, and funding for other community/provincial infrastructure and educational/research initiatives (Government of BC, 2013).

1.1.3 History of Electric Vehicles

Although electric vehicles are being developed with new and emerging technology, they have been in existence for over 100 years. The first EVs were made in the 1800s in England and France, and did not gain popularity in the Americas until the mid-1890s (US Department of Energy, 2005). EVs were most popular around 1899-1900, and were more common than gasoline or steam powered motor vehicles (US Department of Energy, 2005). EVs typically had ranges of around 29 km, with speeds of about 22.5 km/h; they cost between $1000 and $3000 during this time (US Department of Energy, 2005). The EV was a popular choice for many reasons. Compared to its counterparts, EVs were quick to start up and had no gears to shift, any vibration, smell or noisy motor. Their limited range was not an issue, as most driving was local travel on city roads (US Department of Energy, 2005).

EV popularity only lasted until around the 1920s, and the decline was caused by both technology and development. Gasoline vehicles began to be the preferred, as they had a greater range, allowing them to drive further distances on the expanding roadway networks (US Department of Energy, 2005). At this time, the price of gas was decreasing and internal combustion engines were being mass-produced, which factored in to the cheaper cost of gasoline vehicles compared to electric ones (US Department of Energy, 2005). EV production was minimal up until the 1990s, although range and vehicle speed had improved by this time.

The revival of EV production, which occurred in the 1960s and 70s, resulted mainly from the Clean Air Act, the National Energy Program, and regulations created to reduce gasoline consumption (US Department of Energy, 2005). As a result, large automobile companies began producing EVs and business opportunities were created to perform conversions of conventional vehicles to EVs, and with the consistent improvement of technology (US Department of Energy, 2005).

As greater consideration is given to the peak oil concept and climate change, alternative energy vehicles are gaining popularity once again (IPCC, 2007). It is widely known that GHG emissions play a big role in climate change, and that oil and gas resources are non-renewable. Emissions from transportation are the biggest contributor to Canada's GHG emissions, and as of 2010, accounted for 24% of GHG emissions in Canada (Environment Canada, 2012). Additionally, GHG emissions from the oil and gas sector account for 22% of Canada's emissions (Environment Canada, 2012). Combustion engine fuel production and use represent the major contribution of GHG emission. Canada signed on to the Copenhagen Accord in it, and is required to reduce GHG emissions to 17% below the 2005 levels by 2020 (Environment Canada, 2012).

After passing the *Greenhouse Gas Reduction Targets Act* in 2007, the Province of BC aimed to reduce its GHGs by 33% by 2020, and 80% by 2050 (Lee, 2012). By 2010, BC's GHG emissions had decreased by 4.5%, although the province's targets do not account for exports, specifically from those relative to natural gas production (Lee, 2012).

1.2 Efficiency of Photovoltaic Panels

Solar panels for business and residential applications are commonly produced in modules containing around 40 photovoltaic cells, which are also known as solar cells (National Renewable Energy Laboratory, 2013). The name photovoltaic is derived from the process by which solar cells generate their energy; this is achieved by converting light photons into voltage (NREL, 2013). Solar cells are produced using three different material bases including: (1) silicon; (2) amorphous silicon; and (3) cadmium telluride (NREL, 2013). Silicon-based solar cells are the most efficient (NREL, 2013).

The conversion efficiency of a solar cell is represented by the percentage of photon energy that is converted into electrical energy (US Department of Energy, 2013c). The electrical potential of solar cell devices is measured using I-V curves (current-voltage) (US Department of Energy, 2013c). I-V curves are generated by exposing solar cells to constant levels of temperature while varying the resistance of the electricity usage. The current that is measured from the production is used to determine the conversion efficiency (US Department of Energy, 2013c). Solar cell energy conversion efficiency is represented by the following formula (EYE Applied Optics Group, 2007).

$$\eta = \frac{Pm}{E * Ac}$$

The efficiency is calculated by dividing the maximum power point (P_m), by the input light irradiance E (W/m^2) multiplied by the surface area of the solar cell (Ac) in m^2, under Standard Test Conditions (STC) (EYE Applied Optics Group, 2007). STC for PV are 25 °C at 1.5 ATM (EYE Applied Optics Group, 2007). For example, a solar cell that has 10% efficiency with 10 cm x 10 cm dimensions can produce up to 1 watt (EYE Applied Optics Group, 2007). According the National Center for Photovoltaics, the highest efficiency achieved for a PV panel is 43% (National Center for Photovoltaics, 2013).

1.2.1 Industrial Processes, Mining and Metals Used

Various industrial processes are required to produce solar panels, such as mining, refining and electricity generation. Additionally, mining requires other processes including concentration, conversion, reduction, and refining (Dodd, 2013). All of these processes negatively impact the environment directly and indirectly. Mining can be performed through a variety of different methods, but all mining operations generate large quantities of overburden, excavation waste, PAHs, NO_x, and tailings (Dodd, 2013). Some mining practices also require the vegetation and the landscape to be scraped in order to reach the ores underground. Ores contain several impurities such as sand, rocks, and clay (Dodd, 2013). These impurities need to be removed through chemical or physical removal processes to concentrate the metal-bearing ore (Dodd, 2013). Flotation is the most common physical method for separating minerals from ores.

Smelting ore to concentrate the ore also generates slag and atmospheric emissions of sulfur dioxide (SO_2) (Dodd, 2013). Industrial emission of SO_2 can create atmospheric H_2SO_4; the slag is usually disposed of on land (Dodd, 2013). Increased levels of contaminants are often found in adjacent communities and typical contaminants include arsenic, mercury, copper, sulfur dioxide, and PAHs (Dodd, 2013). These processes require machinery that is powered by fossil fuels and factories use electricity to refine the ores.

The removal of the vegetation also exposes the underlying earth to erosive forces such as wind and water. Exposing of sulfide ores to air and water can result in acid mine drainage, which is the most challenging issue associated with the mining industry (Dodd, 2013). Acid mine drainage is represented by the following equation: (Dodd, 2013):

$$4FeS_{2(s)} + 14H_2O + 15O_2 \rightarrow 4Fe\,(OH)_{3(s)} + 8H_2SO_{4\,(aq)}$$

During acid mine drainage, sulfuric acid is produced by oxidizing sulfite ions present in mine tailings and tailings ponds. Pyrite occurs in association with many ores and it is considered the trigger for acid mine drainage, when combined with certain microorganisms. Acid mine drainage lowers the pH of waters and soils, which mobilizes heavy metals into the environment (Dodd, 2013). Dust containing heavy metals can also accumulate on vegetation and from there;

contaminants can enter the food web (Dodd, 2013). Overall, mining will impact ecosystems and reduce biodiversity, as more land is scraped and excavated for minerals (Dodd, 2013).

While both the indirect and direct emission of pollutants results from the production of PVs, the pollution resulting from energy production depends on the country's electricity generation methods. Due to the popularity of the Feed-in Tariff and Micro Feed-in Tariff programs, most solar panels that are produced in Canada are manufactured in Ontario (Momentum Technologies, 2013). Ontario generates a considerable amount of electricity through coal-fired generation, which can introduce heavy metals such as mercury (Hg) into the environment (Health Canada, 2007). At some level, these processes will generate GHG emissions, regardless of where they are produced; therefore, the energy input and materials required to produce solar panels must be optimized in order to mitigate the impacts of panel production on the environment (Dodd, 2013).

1.2.2 Metals and Other Materials in Solar Panels

Various modules are used for production of PVs and the materials used will determine PV efficiency. Some solar panel modules use cadmium telluride (CdTe), while other panels use different crystalline silicon (Si) modules such as ribbon, multi-crystalline Si, and mono-crystalline Si (Fthenakis and Kim, 2006).

The production of CdTe PV solar cells requires the extraction of cadmium (Cd) and tellurium (Te). Cd is generated as a by-product of smelting zinc (Zn) and lead (Pb) ores (Fthenakis, 2006). Most Te is recovered by leaching slimes containing copper (Cu), Te, and other elements, which are generated during the electrolysis of Cu (Fthenakis, 2006). Ninety to 98% of the Cd present in ores is recovered; the rest is contained in mine tailings (Fthenakis, 2006). Cd is also recovered from waste streams during Zn production, as particulates from roaster furnaces and smelting operations (Fthenakis, 2006). Lead is obtained through mining operations, as described in the previous section. Canada is a major producer of metals and ranks as one of the top 10 producers of metals such as aluminum, lead, copper, and gold (Dodd, 2013).

1.2.3 Decommissioning of Solar Panels and Recyclability

Most solar panel equipment is estimated to last at least 20 years and in some cases 30 years, with the proper maintenance (Hatch, 2011). Once the lifespan of the solar panels has been reached, decommissioning is required. In the case where modules cannot be reused, the glass and silicon contained can be reclaimed, and the aluminum frames will be recycled (Hatch, 2011). The disposal of unusable electrical components, such as wires and connectors will create waste and should be properly disposed of according to municipal regulations (Hatch, 2011). Since aluminum is a very recyclable material, there is very little waste produced from the aluminum frames. The decommissioning process will require the use of electricity, which will create air pollution and atmospheric GHGs. Since the number of solar panels used in PV4EV installations is low, the impacts during the construction and decommissioning are relatively small when compared to larger systems.

1.3 Climate Change

Climate change is an important challenge to consider with respect to GHG emissions. This section explains climate change, its implications, and challenges.

1.3.1 What is Climate Change?

Climate change is defined as the change in the state of the climate that persists for an extended period of time, which can range from decades to longer periods (IPCC, 2007). This encompasses changes in the climate that occur over time resulting from natural earth processes and from the effects of human activity (IPCC, 2007). Anthropogenic activities result in the emissions of four long-lived chemical compounds that comprise GHGs: CO_2; CH_4; nitrous oxide (N_2O); and halocarbons including hydrofluorocarbons, chlorofluorocarbons, perfluorocarbons, and sulfur hexafluoride (SF_6) (IPCC, 2007). Atmospheric GHGs accumulate when the breakdown or removal process of these chemicals is slower than the rate at which they accumulate (IPCC, 2007). CO_2 is currently considered to be the most important anthropogenic GHG. Its global annual emission increased 21 to 38 gigatonnes from 1970 to 2004, and encompassed 77% of the anthropogenic GHG emissions (IPCC, 2007). Collectively, increasing concentrations of GHGs and aerosols, as well as changes to land cover, alter solar radiation input to the planet. This modifies the Earth's energy balance, which ultimately results in climate change (IPCC, 2007). These atmospheric constituents influence the absorption, scattering, and emission of radiation inside the atmosphere (IPCC, 2007).

1.3.2 Implications of Greenhouse Gases

The Earth's climate during the late quaternary period was dominated with glacial cycles and intermediate warm periods called interglacial cycles, lasting approximately 100,000 years (Petit, Jouzel, Raynaud, Barkov, Barnola, 1999). Climate naturally changes over time, but it has become apparent that human activity is influencing the rate of climate change (IPCC, 2007). Long-term glacial and inter-glacial climate records have been developed using an ice core sample collected from Vostok Antarctica. This ice core also provides information on atmospheric trace gas composition (Petit, 1999). Since extremely cool weather is characteristic of the Antarctic region, there is reduced precipitation and greater atmospheric circulation; therefore, there is a strong correlation between temperature and atmospheric GHG concentration (Petit, 1999). The research shows that the current atmospheric GHG concentrations are at the highest they have ever been in thousands of years (Petit, 1999). The ice core shows that temperatures during these cycles varied, as did the concentration of carbon dioxide and methane gas (Petit, 1999). Between cold and hot periods, carbon dioxide concentrations ranged from 180 ppm to between 280 and 300 ppm, while concentrations of methane ranged from 280 - 350 ppb to 650-770 ppb (Petit, 1999). This correlation repeated during each climatic cycle, and during the warmest interglacial period, the GHG concentrations were at their highest (Petit, 1999). As of 2007, the atmospheric GHG levels were 379 ppm of carbon dioxide, 1750 ppb of methane, and 319 ppb nitrous oxide (IPCC, 2007). The current concentrations exceed the previous concentrations, which may explain the extreme weather events that we see today.

Climate patterns and response loops to GHG concentrations are largely influenced by atmospheric processes and feedback (IPCC, 2007). Feedback can amplify or reduce a response to natural process. The warming of ocean waters and terrestrial systems reduces the uptake and storage of atmospheric GHGs, and thus results in an increase of the amount of GHGs in the atmosphere (IPCC, 2007). De-glaciation enhancement can also occur as a result of ice-albedo feedback (Petit, 1999). Less ice decreases the albedo (reflectivity of a surface) of the Earth, which increases snowmelt in a positive feedback loop that leads to global climate change (Petit, 1999).

1.3.3 Challenges with Climate Change

There are several environmental challenges that are associated with climate change. Extreme weather events are becoming more frequent and unpredictable, and may be attributed to climate change. These events can harm people, cause damage to infrastructure, and negatively impact the economy (BCMOE, n.d). The Global Reinsurance organization records the number of natural catastrophes that occur worldwide caused by weather, water, or climate. According to the Insurance Bureau of Canada, frequent weather events such as floods, storms, droughts, and warmer weather patterns are at least in part due to climate change (BCMOE, n.d). As a result, payouts from Canadian insurance companies for damages related to weather events have doubled every five years since 1983 (BCMOE, n.d.) The weather events that have the greatest threat in the province of BC are heavy precipitation events, heat waves, and drought. Such weather events are linked to flooding, landslides, water shortages, and reduced air quality (BCMOE, n.d). Individuals, businesses, and governments inevitably absorb the expenses that result from these weather events. Increasing greenhouse gas emission threatens climate and is predicted to cause even more damage in the future (BCMOE, n.d.).

Along with high costs, climate change additionally threatens ecosystems that support our communities and economy. In BC, ecosystems are highly valued as they provide necessities and services such as clean water, air, resources, and even flood control (BCMOE, n.d). These ecosystem services are highly expensive to replace and in some instances, are not possible to replace (BCMOE, n.d). Short periods of winter that result from climate change are predicted to impact agricultural by lowering available runoff water for the summer. Additionally, short winters will also impact the hydropower and fishing industry, as well as the local communities (BCMOE, n.d).

Extreme weather events such as heavy precipitation and heat waves can also impose serious health and safety risks. Heat waves are known to induce heat stroke and also decrease air quality, which leads to respiratory problems. During a heat wave in 2009, the Vancouver International airport recorded temperatures as high as 38.4 degree centigrade (BCMOE, n.d), which may be attributed to climate change. Extreme temperatures can increase the likelihood of forest fires and can cause serious damage to ecosystems. One forest fire in southern BC led to the evacuation of approximately 45,000 people (BCMOE, n.d). More recently in 2010, smoke blanketed the City of Vancouver resulting in significant air quality warnings (BCMOE, n.d).

According to the IPCC (2007), it is likely that the frequency of extreme weather events will increase and become common within many regions. It is also mentioned that the duration and frequency of heat wave events will likely increase as well (IPCC, 2007). These challenges and issues associated with climate change collectively make addressing these problems an even greater challenge.

1.4 Project Sponsor and Advisor

Colwood is a small city ten kilometers west of Victoria, BC. The city was incorporated in 1985, and is one of 13 municipalities that are part of the Capital Regional District (City of Colwood, 2006). The City of Colwood, along with Solar Colwood, sponsored the PV4EV project, with Councillor Judith Cullington acting as the liaison and project advisor. Councillor Cullington was elected to City council in 2008, and re-elected in 2011. She is the council lead for Solar Colwood, which is a City project that offers incentives, products, financing, and advice to residents and business owners in Colwood for various energy saving actions (Solar Colwood, 2013). One goal for the project is to provide 1000 property owners in Colwood with grants to install home solar energy systems. Another goal is to develop electric vehicle recharging infrastructure within Colwood (Solar Colwood, 2013). Currently, there are ten charging stations within Colwood, which are available to the public and use on-grid electricity. However, LiveSmartBC along with Solar Colwood, through a partnership with Natural Resources Canada, offer rebates for home and business owners for the installation of PV4EV (Solar Colwood, 2013). This partnership will allow for the installation of ten PV4EV in the City of Colwood. Currently, there are six PV4EV already installed under this program, with one located at Royal Bay Bakery. The panels are used to charge the owner’s electric vehicle, with additional residual power being reverted into the electricity supply for the bakery (Royal Bay Bakery, n.d.).

1.5 The Carbon Neutral Framework

The Becoming Carbon Neutral framework was developed by the GCC in order to assist local governments; it describes four steps for communities to follow to assist them in achieving their carbon neutrality target. Step 1 consists of measuring the annual corporate emissions by determining energy consumption by using an emissions measurement tool (e.g. SMARTTool) to calculate emissions (Green Communities Committee, 2011). Once the corporate emissions have been calculated, local governments are encouraged to reduce their corporate GHG emissions by implementing a variety of actions and strategies, such as improving energy efficiency in buildings and switching to fuel efficient vehicles (Green Communities Committee, 2011). After a local government has reduced its corporate emissions as much as possible, emissions may still be produced from ongoing operations. In order for local governments to reach their carbon neutral target, they can either balance or offset current GHG emissions by an equivalent emission reduction from validated and measurable GHG emissions projects (Green Communities Committee, 2011).

The Becoming Carbon Neutral framework outlines three options for local governments to undertake to reduce their corporate emissions. The GCC has designed Option 1 projects to be flexible, easy to implement in communities, and consist of credibly measured GHG emissions reductions methods. Option 1 projects that are supported by the GCC include four project types: energy efficient building retrofits; solar thermal retrofits for heating hot water; household organic waste composting; and LEVs (Green Communities Committee, 2011). Local governments that wish to reduce their emissions with alternative projects other than the projects described in the Option 1 category fall under Option 2- Alternative Community GHG Reduction Projects (Green Communities Committee, 2011). In order for local governments to implement Option 2 projects for reducing corporate emissions, they must ensure that the proposed project meets all seven project eligibility requirements outlined in the framework and it must be validated by a third party (Green Communities Committee, 2011). For emissions that were not reduced using Option 1 and/or Option 2 projects, local governments can offset the remaining corporate emissions by purchasing carbon offsets from a verified carbon offset provider, such as the Pacific Carbon Trust (Green Communities Committee, 2011). Option 3 carbon offsets are the simplest, and may be the least expensive method compared to Option 1 and Option 2 projects, for local governments to use towards their carbon neutral target (Green Communities Committee, 2011). Carbon offsets are high-quality emission reduction projects, measured in tonnes of carbon dioxide equivalents (CO_2e), generated through projects that avoid or sequester GHGs. They can be purchased to offset the remainder of corporate GHG emissions in order to achieve carbon neutrality. However, Option 3 projects do not directly reduce local GHG emissions. Lastly, local governments must report their annual corporate emissions, as well as actions that have been taken to reduce these emissions, and ensure that these reports are available to the public (Green Communities Committee, 2011).

1.6 Government Carbon Reduction Legislature, Programs, and Initiatives

Various tools that address carbon emissions are outlined in the following sections. These include the BC Climate Action Charter, Climate Action Revenue Incentive Program, LiveSmartBC, Community Energy and Emissions Inventory, and Bills 44 and 27.

1.6.1 BC Climate Action Charter

Local governments across BC have partnered with the Union of BC Municipalities (UBCM) in order to reduce corporate and community-wide GHG emissions (LGD, 2013a). Currently, 180 out of 188 municipalities in the province have signed the BC Climate Action Charter (LGD, 2013a). By signing the Climate Action Charter, local governments have been committed to becoming carbon neutral by 2012, through developing compact and energy efficient communities, and measuring and reporting community-wide GHG emissions (LGD, 2013a). In addition, the Provincial government launched the Climate Action Revenue Incentive Program (CARIP) to provide funding to the municipalities that have signed the Charter; they will be reimbursed 100% of paid carbon taxes (LGD, 2013b).

1.6.2 Climate Action Revenue Incentive Program

Climate Action Revenue Incentive Program (CARIP) is a conditional grant program that provides the communities and municipalities that have signed the BC Climate Action Charter with a grant of 100% of the paid carbon taxes during the previous year (Ministry of Community, Sport & Cultural Development, 2012). In order to be eligible to receive the grant, local governments must be a signatory of the BC Climate Action Charter, which entails carbon neutrality by reducing their corporate and community-wide emissions, and reporting their plan and process to the public and the provincial government (Ministry of Community, Sport & Cultural Development, 2012). All local governments were required to sign the BC Climate Action Charter by December 31, 2012, in order to claim the grant for carbon taxes paid in 2012 (Ministry of Community, Sport & Cultural Development, 2012). As part of the grant eligibility process, local governments were required to fill out and submit the CARIP Public Reporting Template to the government and make the report available to the public by March 8, 2013 (Ministry of Community, Sport & Cultural Development, 2012). Once completed, local governments are required to make the report available to the public and resubmit their updated Interim CARIP Report to the Province by June 1st of the following year (Ministry of Community, Sport & Cultural Development, 2012). Local governments that do not submit their finalized CARIP Report may not be eligible for the following year's CARIP grant, nor will they be included in certain aspects of the Green Communities Recognition Program, and will not be included in the following year's provincial level report (Ministry of Community, Sport & Cultural Development, 2012).

1.6.3 LiveSmartBC

LiveSmartBC is a program that helps citizens in BC make environmentally and economically beneficial choices in their lives. There are many initiatives in the program that address home, work, transportation, and education. Incentives and rebate programs are available through LiveSmartBC to make these choices (BC Government, n.d.a).

1.6.4 Community Energy and Emissions Inventory

Community Energy and Emissions Inventory (CEEI) reports are estimates of the energy use and greenhouse gas emissions within a community over a period of one year (BC Ministry of Environment, 2010). In 2012, annual corporate carbon emissions for the City of Colwood were 210.51 tonnes CO_2e (City of Colwood, 2012). The possibility of offsetting these emissions through the use of PV4EV was explored in this report.

1.6.5 Bill 44 GHG Reductions Target Act

The Bill 44 Greenhouse Gas Reduction Targets Act was legislated in 2007 for the reduction of GHG emissions in BC's Public Sector Organizations (PSOs) and establishes GHG emission reduction targets for 2020 and 2050 (LGD, 2013c). By 2020, GHG emissions for PSOs and provincial government in BC must be at least 33% below 2007 emission levels and an 80% reduction from 2007 levels by 2050 (LGD, 2013c). Starting in 2008, the Act required all PSOs, including the provincial government, to begin reducing emissions to become carbon neutral with respect to business travel by public officials (LGD, 2013c). For the following years, PSOs were required to submit a carbon neutral action report with a description of the actions taken to reduce GHGs, as well as a long-term plan to continue reducing emissions (LGD, 2013c).

1.6.6 Bill 27 Local Government (Green Communities) Statutes Amendment Act

As a result of Bill 27 amendments to the Local Government Act and Community Charter in 2008, local governments were required to establish GHG emission targets within their Official Community Plan (OCP) by 2010, and within their Regional Growth Strategy (RGS) by 2011. Bill 27 also included actions and policies for achieving their reduction targets (Rutherford, 2009). In addition, local governments are required to inventory their GHG emissions by using resources such as the CEEI reports, which describe the energy consumption and emissions of activities in individual communities (Rutherford, 2009).

1.7 Corporate Municipalities Offset Purchasing

Most communities in BC had voluntarily committed to becoming carbon neutral by 2012, at which time carbon neutrality became mandatory. Carbon neutrality involves the measuring of operational GHG emissions, and reducing them where possible, or offsetting the remainder, as described in section 1.4 (BC Government, n.d.a). Of 188 municipalities, 180 of them have signed the BC Climate Action Charter, which commits the municipality to measuring and reporting on their community's GHG emissions profile (BC Government, n.d.b). In order to measure GHG emissions, PSOs, which include government offices, schools, post-secondary institutions, Crown corporations, and hospitals, must measure energy use from buildings, fleets, equipment, and paper. Government ministries and agencies must also measure emissions generated from travel (BC Government, n.d.a). To do this, the BC Government has developed two online measurement tools: the SMARTTool and SMARTTEC. SMARTTool measures emissions from buildings, fleets, and paper, whereas SMARTTEC is used for travel emissions (BC Government, n.d.a).

It is not currently possible for PSOs to achieve carbon neutrality through reducing energy use, therefore, they must invest in high-quality emission reduction projects, or offsets, through the PCT (BC Government, n.d.a). The PCT is a Crown corporation that was created by the BC Government in 2008 in order to access credible GHG offsets from different communities in BC (BC Government, n.d.a). All projects available through PCT meet strict requirements as defined by the Ministry of Environment's Offset Emissions Regulation (BC Government, n.d.a). The offsets are available for purchase at a price of $25 per tonne of CO_2e (PCT, 2013). Examples of projects include companies switching to biomass fuel, improving greenhouse efficiency, and hybrid heating systems (PCT, 2013). Offset purchasing is the third option under the Becoming Carbon Neutral framework for local governments to use to achieve carbon neutrality (GCC, 2011). The BC Government and the Union of BC Municipalities joined to create the GCC, which developed this framework for municipalities to use to reach their BC Climate Action Charter commitments (GCC, 2011). Under the Option 3 criteria, local governments can purchase offsets from PCT or another offset company (GCC, 2011).

1.8 Current & Future Electricity Demand

When considering changing from one energy source, such as fossil fuel, to another, such as electrical energy, the future demand, resiliency, and sustainability has to be considered. This section introduces the environmental impacts of building new hydroelectric infrastructure, as would occur in BC given increasing demand for electricity, as well as how population growth will affect the increase in demand for electrical energy. Discussed are the implications of increasing electricity demand for transportation, the impacts associated with its generation, and to what degree this may possibly be lessened through the use of PV4EV.

1.8.1 Environmental and Social Impacts of Hydroelectricity

In BC, approximately 90% of energy is generated by hydroelectric means (BC Hydro, 2013b). The hydroelectric installations in the Peace River and Columbia River Basins supply approximately 80% of BC Hydro's installed generating capacity (BC Hydro, 2013b). Despite being seen as a sustainable or "green" source of energy, hydroelectric power does have some significant environmental impacts. These can be classified as either footprint or operational effects. Footprint impacts are those that arise due to the structures themselves, and persist until the decommissioning of the project (Ecofish Research Ltd., 2012). Examples of footprint impacts include the effects on the riparian and aquatic habitat areas that are flooded behind the intake weir or the habitat that is occupied by the intake structure and tailrace (Ecofish Research Ltd., 2012). Operational impacts are those that are not directly related to the project structures, and are possible to alter in some way. Examples of these include impacts arising downstream of the intake in the diversion reach, and downstream of the powerhouse (Ecofish Research Ltd., 2012). The impacts can also be classified by the specific aspect of the environment, in which the effects are being felt, such as: impacts on the hydrological system and river dynamics; on physico-chemical cycles; on soil, surface and groundwater quality, and environmental toxicity, or on ecosystems (Wildi, 2010).

The impacts on the hydrological system and river dynamics are numerous, with effects occurring both upstream and downstream. Upstream, rivers may be diverted to supply more water to the reservoir or to increase capacity, which can result to changes in landscapes, surface water, and groundwater systems. (Wildi, 2010). Rivers may also be diverted downstream in order to gain elevation and pressure, or for navigation and irrigation, all resulting in changes to the river dynamics downstream (Wildi, 2010). When reservoir water is exploited for irrigation, storage, or producing electricity, downstream river stores can diminish greatly, as occurred with the reduction of floods of the River Nile (Wildi, 2010).

Impacts on physico-chemical cycles occur when the storage of water in the reservoirs lead to accumulation of organic materials, nutrients, and contaminants, which can result in a decrease of downriver transport of nutrients and sediments, or an increase risk to human exposure to contaminants if used for irrigation or other purposes (Wildi, 2010). Reservoirs have been shown to trap 70 to 90% of the sediment volume delivered to the watershed. This results in 30 to 40% of the suspended matter transported by rivers not reaching the oceans or major lakes, as they are retained in the reservoirs, and a subsequent reduction in primary production and species composition (Wildi, 2010). By slowing the movement of natural waters, sediment distribution to deltas, estuaries, flooded forests, wetlands and inland seas are severely impacted (WWF, 2004). Furthermore, the flushing of a reservoir can then result in massive sediment transport, damage to ecosystems, and increased erosion of riverbanks (Wildi, 2010). These factors influence the nutrient balance and geochemical cycling upstream and downstream, which can significantly impact aquatic species in the river. Erosion along the riverbed upstream and downstream can also disturb wildlife and aquatic populations (EPA, 2012). The storage of water in the reservoir and subsequent release can result in sudden changes in downstream temperatures, oxygen content, and salinity, all of which can affect the ecosystems downstream (Wildi, 2010). The temperature of the reservoir water is often much colder than the water downstream, and may kill fish and other organisms when released from the dam (EPA, 2012).

Hydroelectric dams can also have impacts on soil, surface and groundwater quality, and environmental toxicity. Damage to soil quality can occur from salinization in arid conditions when evaporation and evapotranspiration are high, due to irrigation and the maintenance of increased groundwater levels. Also, contamination of floodplain soil can occur when flooding occurs, due to the accumulation of contaminants in the reservoirs (Wildi, 2010). The quality of surface water and groundwater can be jeopardized by sediment imbalances as fine fractions of sediment (fine silt and clay) increase. This results in an increase in fine sediments at the outlet of the reservoir, which highly adsorb toxic contaminants (Wildi, 2010). Water turbidity can also increase, resulting in high populations of plankton, and possibly mosquitoes and other insects (Wildi, 2010). Groundwater levels generally rise in areas downstream of reservoirs due to the damming, increased infiltration, and rise of the hydraulic base level (Wildi, 2010). Increased dissolved oxygen (DO) concentration of the infiltrate during the filling of the reservoir can result in decreased oxygen levels, which can lead to increased ammonium concentrations and remobilization of iron and other contaminants, thereby diminishing drinking water quality (Wildi, 2010). This can also result in habitat that is inhospitable for fish and other aquatic organisms due to the low oxygen levels, and can kill fish and organisms when the oxygen poor water is released back into the river (EPA, 2012). Environmental toxicity can occur from contaminants in reservoirs and anoxic (decreased oxygen) conditions (Wildi, 2010). Anoxic conditions in the reservoir can also result in the formation of hydrogen sulfide (H_2S) gas that degrades water quality, and anoxic conditions downstream can diminish the ability of the waters to process waste (WWF, 2004).

Ecosystem impacts can vary depending on the scale of the operation, and are influenced by the aforementioned impacts. They can include loss of forests and wildlife habitat, loss of populations, degradation of upstream and downstream habitat, loss of aquatic biodiversity, loss of fisheries, and a loss of ecosystem services from floodplains, wetlands, riverine, estuary, and adjacent marine ecosystems (Wildi, 2010). Water retention also leads to decreased recharge of wetlands, groundwater, and surface waters (WWF, 2004). The construction and operation of hydropower plants can require substantial land, and can result in the flooding of large areas that were wildlife habitat, farmland, or provided other ecosystem services (EPA, 2012). One significant impact is the effects on salmon populations, which depend on rivers for their life cycle. Large dams in the Columbia River Basin have led to significant declines in salmon populations, as young offspring are killed by turbine blades, and adults are obstructed from swimming upstream to reproduce, by the dams (EPA, 2012).

The Site C Clean Energy Project is a proposed third dam and hydroelectric generating station that will be located on the Peace River in northeast BC (BC Hydro, 2013b). If this project were approved, Site C would supply 1100 megawatts of capacity and produce approximately 5100 GWh/year (BC Hydro, 2013b). This would be enough energy to power approximately 450,000 homes per year in BC. The project is being proposed due to the expected increase in the electricity requirements by 40% over the next 20 years. The current supply of electricity in BC is not sufficient to supply these future needs, if demand continues to grow as expected (BC Hydro, 2013b). The expected financial costs associated with this project are around $7.9 billion (BC Hydro, 2013b). One significant benefit of this project, and of hydroelectricity in general, is the substantial reduction in GHG emissions from this form of energy compared to others. BC Hydro estimates that 8gCO_2e/kWh will be generated from the Site C dam. As a comparison, tropical hydroelectric generating facilities generate approximately 2150gCO_2e/kWh and coal generates 1000gCO_2e/kWh (BC Hydro, 2013b).

There are however, many significant environmental and social costs that are not included in the economic valuation. One concern is the transformation of the river ecosystems. This is expected to result in the loss of three distinct sub-groups of species: the migratory Arctic grayling in the Moberly River; the migratory bull trout that spawn in the Halfway River, and the mountain whitefish (BC Hydro, 2013b). The construction of the dam will also affect migratory bird habitat, which will impact migratory species at risk birds such as Canada, Cape May, and Bay-breasted Warblers, Yellow Rail, and Nelson’s Sparrow (BC Hydro, 2013b). Construction is also expected to fragment unique terrestrial ecosystems that include mari fen, tufa seeps, and mature riparian and floodplain forests (BC Hydro, 2013b). This will directly result in the loss of two plant species at risk: the Drummond’s thistle and the little bluestem (BC Hydro, 2013b).

Significant social costs will result from the construction of the Site C dam. Important multi-use, cultural areas and landscapes valued by members of the Treaty 8 Tribal Association, Saulteau First Nation, Blueberry River First Nation, Duncan’s First Nation, Horse Lake First Nation, and Dene Tha’ First Nation will be lost, such as the Attachie, Bear Flats, and Farrel Creek (BC Hydro, 2013b). This will affect hunting, trapping, and fishing opportunities, as well as cultural practices (BC Hydro, 2013b). These high value places will be inundated and access to them will be permanently changed, according to BC Hydro (2013).

Hydroelectricity appears to be a source of energy with much less environmental concerns compared to alternatives, such as fossil fuels, especially if considering GHGs. However, there are significant environmental and social impacts associated with hydroelectric power that need to be recognized and addressed when considering its use for supplying BC's energy demand.

1.8.2 BC Current and Future Energy Usage

As the population of BC, and more specifically the City of Colwood, the Westshore Communities, and the CRD grow in size, electricity demand will also increase. This will likely lead to the development of new hydroelectric dams, run of river systems, or further burning of fossils fuels to generate enough supply to meet the demand. According to the 2006 census, the population in Colwood was 14,687, and in 2011 it had increased to 16,093; an increase of 9.8% in only 5 years (Capital Region District, 2012). The City of Colwood estimates an annual growth rate of 4% (City of Colwood, n.d.). The same census years showed that the Westshore communities cumulatively grew by a staggering 17.4% (Capital Region District, 2012). According to CRD population projections, Colwood will see an increase in population to 30,200 by 2026. The Westshore Communities are expected to grow to 112,300, which is more than double their population in 1996, with the CRD as a whole reaching a population size of 427,800 by 2026, up from 331,820 in 1996. The core of the CRD including Esquimalt, Oak Bay, Saanich, and Victoria, was predicted to grow the least from 1996 to 2026, with an increase from 217,670 to 244,200 (Capital Region District, 2001). It is evident that the majority of the growth in the CRD is focused in the study area, and the implementation of PV4EV systems in Colwood and the Westshore Communities will have the greatest impact as new residential areas are developed. Since PV4EV systems are not directly associated with each individual, but instead with the number of households, the household growth rate was also considered. In 2006, the CRD determined there were 159,843 households and they predicted a 36% growth rate in 30 years, to 217, 819 households (Capital Region District, 2008). The average electricity consumption per household can then be used to determine what the projected electricity demand will be at the final year of projected household growth.

According to Statistics Canada, the average Canadian energy use per household annually, including apartments, multifamily units, and single detached houses across all provinces, was 106 GJ in 2007; an equivalent of 29,468 kWh per year (1GJ = 278 kWh) (Statistics Canada, 2007; Government of Alberta, 2013). It then may be inferred that 36% growth in households from 2006 to 2036, as predicted by the CRD, will require a 36% increase in electricity to support the growth and development within the CRD. This would require an additional 1700 GWh to be generated on the island, or delivered from the mainland. With a typical array of six 250 W solar panels and an average of 5 h of sunlight per day, approximately 3000 kWh can be produced per year, creating a 10% reduction in household energy costs when the PV4EV system is not charging a vehicle. With the expected 17% price increase for electricity delivered by BC Hydro over the next three years, the payback period for the solar array will likely decrease (BC Hydro, 2013a).

According to Statistics Canada (2006), 24% of GHG emissions in Canada are due to the transportation sector; 52% of which is due to passenger transport. In BC in 2006, 83% of all households owned or leased at least one vehicle; in Victoria, 64% of the population travelled to work by single occupancy vehicles, a third of which commuted more than 20 km (Statistics Canada, 2006). Based on the household growth rate, and the number of people per household in the CRD, it may be possible to estimate the household growth rate in Colwood through the following equations, assuming linearity and the same number of individuals per household as the CRD:

Annual Household Growth Rate in the CRD

(217,819 households in 2036 – 159,843 households in 2006)/ 30 years = 1932.5 households per year

Annual Population Growth Rate in the CRD

(427,800 people in 2026 – 331,820 people in 1996)/30 years = 3199.9 people per year

Number of People per Household in the CRD

(3199.9 people/year) / (1932.5 households/year) = 1.66 people per household in CRD

Annual Population Growth in Colwood

30,200 in 2026 - 16,093 in 2011 = 14,107/25 years = 564.3 people per year

Household Growth Rate in Colwood

(564.3 people per year)/ (1.6 people per household) = 367.4 households per year in Colwood assuming same number of people per household as CRD

If 83% of households within Colwood own or leased at least one vehicle, there would currently be approximately 10,058 vehicles within Colwood, and in 30 years this number may double to 21,080. Assuming each vehicle travels an average of 20,000 km annually, and 681gCO_2e are emitted per kilometer (assuming an average of 8.93 km/L), there would be 287,109.6tCO_2e being emitted annually in Colwood from vehicles 30 years from now, up from 136,990 tonnes annually today (US EPA, 2011). With PV4EV, this huge increase in CO_2e emissions from vehicles could be mitigated.

As previously mentioned, a typical 6 panel, 250 W solar array, could produce 3000 kWh annually. Comparing this to the fuel economy of electric vehicles currently available in Canada, it can be estimated that at least 75% of the energy needed to offset an EV completely, could be achieved. It should be considered that many commuters travel less than 20,000 km annually, and that there is typically more than 5 hours of daylight available. Also, an EV could be charged at work or community EV charging stations, which are becoming more abundant, so it is theoretically possible to offset all energy needed for an EV with a typical solar array.

Average Annual EV Electricity Use

(Avg. 20,000 km per year travel)* (0.62 miles/km)*(Avg. combined Highway/City (32.6 kWh/100miles)) = 4,042 kWh used by EV annually on average

3,000 kWh/4,042 kWh estimation *100 =

74.2% from solar array

Table 1. Conversion equivalencies in miles per gallon of gasoline equivalent (MPGe) for 2013 electric vehicles available in Canada, including the Ford Focus, Mitsubishi i-MiEV, Nissan Leaf, Tesla Model S, and Smart Fortwo, in terms of one gallon being equal to 33.7kWh, according to the U.S. Department of Energy (2013), on May 14, 2013.

2013 Electric Vehicle Model Available In Canada	Combined Highway/City Economy kWh/100mi	Equivalent Gasoline Mileage (mpg)
Ford Focus	32	105
Mitsubishi i-MiEV	30	112
Nissan Leaf	34	99
Tesla Model S	35	95
Smart Fortwo	32	107

GHGs produced by the electricity provider, BC Hydro in this case, must also be considered. BC Hydro as a business is essentially carbon neutral, as required by the Greenhouse Gas Reduction Targets Act. This is mainly achieved through the purchase of carbon offsets. It was found that 74% of their reported GHGs came from fleet vehicles, 24% from buildings, and 1% from paper use. In 2010, BC Hydro generated 30,672 tonnes of GHGs, 29,974 of which needed to be offset; therefore $749,344.50 was spent to purchase 30,000 offsets (BC Hydro, 2010). In 2012, the production of approximately 50,000 GWh generated about 560,000tCO_2e, which is around 11.2 tonnes per GWh. In 2011, 1,074,000tCO_2e were emitted, as shown in Figure 1. It has been reported that a range of 20 to 30 tonnes per GWh is generated year to year by BC Hydro and its Independent Power Producers. This is significantly lower than Canadian coal-fired generation, which ranges from 800 to 1000tCO_2e/GWh. These reported emissions from BC hydro include CO_2e emissions from stationary combustion, such as natural gas, purchased electricity from natural gas plants, biomass electricity producers, and diesel generation in non-grid tied areas (BC Hydro, 2012).

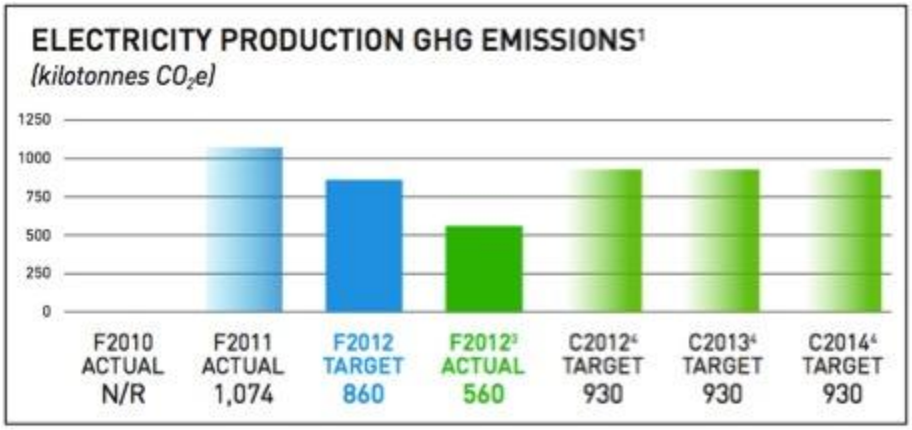

Figure 1. Actual and target kilotonnes of CO_2e emissions for BC Hydro and its associated power producers in 2010, 2012, 2013, and 2014 from stationary combustion such as natural gas, purchased electricity from natural gas plants, biomass electricity producers, and diesel generation in non-grid tied areas. Figure obtained from BC Hydro, 2012; superscripts are not relevant to this report.

Considering the potential requirement of 1700 GWh needed to supply development by 2036 within the CRD, the associated GHG emissions from such an increase would roughly equate to 34,000 to 51,000tCO_2 annually by 2036. Currently, Vancouver Island is only able to produce 30% of its electricity requirements, and this amount is expected to decline as population increases, as both energy demand and population are inextricably linked. As the current system of undersea cabling to deliver energy from the mainland reaches the end of its usable life, the resiliency of electricity on Vancouver Island will become questionable (The Greater Victoria Chamber of Commerce, n.d.; Whiticar, 2012). The current electrical grid is illustrated in Figure 2.

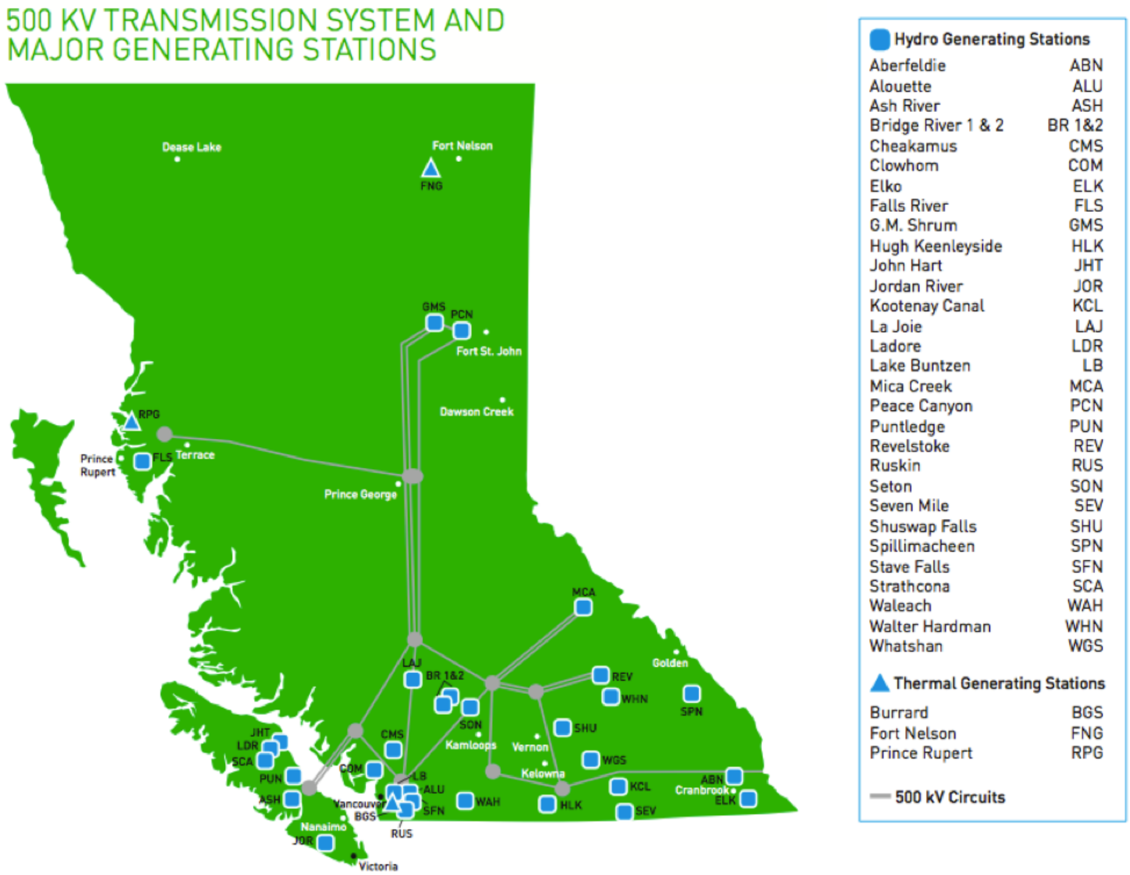

Figure 2. The 500 kilovolt (KV) transmission systems and major hydro generating stations located throughout BC, as well as three thermal generating stations on May 14, 2013 (BC Hydro, 2012).

Generally, critics of PV4EV and PV persistently suggest that it is an unreliable system, as sunshine is intermittent, and that methods of storing the energy are required for the systems to become economically viable (Chung, 2013). For example, the electrolysis of water is the up-and-coming method to combat this issue. Splitting a water molecule with electricity can form hydrogen and oxygen gas. In this case the electricity will be supplied from the solar array when it is in abundance. The gases can be stored in tanks and recombined later to generate heat or electricity. Typically, hydrogen fuel cells as described above, are expensive to make due to the requirement of catalysts made from expensive and toxic metals, such as ruthenium and iridium. Research performed by two chemists at the University of Calgary, suggests that through a new process, the current catalysts can be replaced with non-toxic ones, such as one made from iron oxide (rust). This new process is expected to reduce the expense of producing hydrogen fuel cells by 1000 times, and residential systems are currently being developed (Smith, Prevot, Fagan, Zhang, Sedach, Siu, Trudel, & Berlinguette, 2012).

GHG emission reductions and energy security are two issues that may be addressed through new technologies, such as PV4EV. Electricity can be produced from a renewable resource, and transportation can essentially become emission free. As society begins to see these technologies become more familiar, the adoption of them will likely increase. The remainder of the report will discuss how this is currently being implemented in Colwood, BC.

2.0 Scope of the Project

The sponsor has retained the major project team to determine the GHG emissions reduction from the implementation of ten PV4EV systems within the City of Colwood. The project timeline was from January 2013 to August 2013. A literature review of the current electricity supply within BC was conducted and used to examine the feasibility and benefits of utilizing PV4EV. Current EV owners who do and do not currently use PV systems to power their EV were interviewed for information pertaining to their EV usage. Recommendations were made with considerations being given to the financial, social, and ecological implications of hydro and fossil fuel generated electricity, which supplies southern Vancouver Island, and future electricity demand implications.

3.0 Research Questions

The research and results compiled in this report will provide answers to the following research questions listed below.

1. What are the greenhouse gas emission reductions that can be achieved in one year by the implementation of ten PV4EV systems in Colwood, BC?

2. What are the potential greenhouse gas emission reductions that can be achieved if PV4EV was implemented across the Capital Regional District to accommodate current electric vehicle owners?

3. What are the environmental, social, and financial issues associated with the current electricity supply in Victoria? In BC?

4. What are the expected electricity demand projections for Colwood and how can this be mitigated by the use of photovoltaics?

4.0 Research Design and Methodology

To address the research questions previously outlined, literature reviews, interviews, and a short questionnaire/survey were used to obtain data and information. The literature review largely involved seeking credible information through government, academic, and corporate websites. Some insight into considerations have also come from online news articles and opinion pieces, but these sources were only used as seeds for delving into a topic or idea more deeply. Data obtained from the questionnaires were intended to provide a quantitative measurement pertaining to the GHG emissions avoided by actual users who transitioned from an ICE to an EV, with or without PV. Qualitative information was also obtained through the interview process to determine perceived barriers and advantages to utilizing PV4EV. These methods have been covered in more detail below.

4.1 Measurement

The BC Climate Action Toolkit includes a worksheet that quantitatively estimates the vehicle CO_2e emissions avoided, and demonstrates the amounts of emissions produced by a variety of vehicles using different fuel types. Upon entering manufacturer fuel efficiency ratings of a particular vehicle and fuel type, such as an electrified Nissan Leaf or a standard Honda Civic, the worksheet is able to calculate the amount of emissions produced by each, and reports the difference between the two, including the amount avoided by use of the EV rather than the ICE. This is accomplished using standardized conversion values for comparison of different fuel types, total annual distance driven, and the proportion of driving between highway and city. It may also be utilized for fleet vehicles. This is a useful worksheet for organizations and individuals to calculate the amount of emissions that would be avoided by using alternatively fueled vehicles rather than gasoline fueled ones. This information can then be applied as a solution to offset carbon emissions at the source, rather than investing financially in carbon offsets through a private carbon offset provider. A sample of the worksheet has been included in Appendix C, and demonstrates the difference in emissions, and emissions avoided by replacing a fleet of ten average ICEs with ten Nissan Leafs. In this study, it was used to determine avoided emissions for each of 15 interviewees that had made the transition from an ICE to an EV in the GVA.

4.2 Data Collection

To obtain the necessary data for an analysis on EV use, the team attended a Vancouver Electric Vehicle Association (VEVA) Vancouver Island Chapter meeting, and distributed questionnaires to members. Surveys were also distributed electronically to members of VEVA and the Nissan Leaf Club, a member-only email distribution list for the GVA. The questionnaire asked current EV users about the type of EV they currently owned, their previous or currently owned ICE vehicle, an odometer reading per specific time period (e.g. km/month or km/year), proportion of city versus highway driving, proportion of driving EV versus ICE (if they still own one), average kWh used to charge their EV, and finally, barriers to owning PV4EV. Fifteen responses were received in total and used for calculations for the project. Appendix A is a copy of the question sheet that was given to members of the VEVA Vancouver Island Chapter when the team attended their meeting. Appendix B is a copy of the email survey sent to members of VEVA and the Nissan Leaf Club. Appendix D is a summary of the raw data responses received and used in the project.

A literature review was conducted to obtain statistical information and data for the project. Government websites such as the City of Colwood and the CRD, along with Statistics Canada, were largely used for obtaining statistical data on population growth, energy usage, and other demographical information. The City of Colwood also provided information regarding corporate GHG emissions through the CEEI report. The BC Hydro website was used extensively to obtain information regarding BC's current energy supply, information on hydroelectricity, and GHG emissions. Finally, the US EPA and Department of Energy websites provided valuable information on vehicle and driving statistics and emissions data. Many other sources were used for this project, along with important documents, such as the Becoming Carbon Neutral guidelines produced by the GCC.

5.0 Results

Following completion of the interviews and data collection, it was estimated that for every ten installations, the CO_2e emissions avoided by eliminating ICE vehicles and replacing them with PV4EV is on average 35.14 to 35.38tCO_2e per year. To expand on the potential their PV4EV system has for mitigating GHG emissions, this project consider the effects fundamental on a larger scale.

5.1 GHG Reductions from PV4EV in the City of Colwood

Through interviewing two current users of PV4EV, and 13 other EV users, as well as completing the necessary analysis, it has been estimated that for every ten PV4EV installations within the City of Colwood, 35.14 to 35.38tCO_2e emissions per year could be avoided. Table 2 identifies the data obtained from the 15 interviewees. To find the average avoided emissions in tCO_2e per year for ten EV users, the difference was taken between the average ICE and EV annual emissions per one EV, and multiplied by ten. By having the ten EV systems fuelled by PV, an additional 0.486 to 0.729 tonnes, or 486 to 729 kg of CO_2e emissions per year are avoided, as determined by the LEV worksheet. A total of 35.14-35.38tCO_2e emissions would be avoided per year for every ten transitions from ICE to PV4EV.

Table 2: Average emissions in tonnes of carbon dioxide equivalents (CO_2e/year) and average emissions for each participant using their previous/current combustion engine vehicle, their current electric vehicle, and the avoided emissions from utilizing the electric vehicle versus the combustion vehicle, and the extrapolation of the averages to determine the emissions from 10 people in the City of Colwood, on May 14, 2013.

Participant	ICE Emissions Tonnes CO_2e/year	EV Emissions Tonnes CO_2e/year	Avoided Emissions Tonnes CO_2e/year
1	5.08	0.14	4.94
2	3.38	0.06	3.32
3	4.18	0.09	4.09
4	5.2	0.1	5.12
5	3.77	0.06	3.71
6	1.24	0.03	1.21
7	4.49	0.12	4.37
8	2.44	0.08	2.36
9	4.45	0.08	4.38
10	6.82	0.12	6.7
11	1.52	0.03	1.49
12	3.29	0.06	3.23
13	2.39	0.06	2.33
14	3.32	0.09	3.23
15	1.55	0.05	1.5
Average per 1 EV	3.54	0.078	3.47
Average per 10 EVs	35.41	0.78	34.66

5.1.1 GHG Reductions from PV4EV across Various Scales

Statistics Canada reported that in 2007, the households' privately owned vehicles within the metropolitan area of the City of Victoria and the Province of BC were responsible for 625,000 and 6,802,000tCO_2e emissions, respectively (Statistics Canada, 2012a). Statistics Canada also reported that in 2007, greenhouse gas emissions intensity from households' private vehicle operation in Canada was 70,774KtCO_2e emissions annually, up from 52,256 Kt in 1990. Figure 3 demonstrates the exponential growth of CO_2e emissions from 1990 to 2007 that are produced by households' privately owned vehicles (Statistics Canada, 2012b). This has been forecasted to the year 2020, which resulted in an estimated 90,000 Kt being produced annually from private vehicles in Canada. The high r-squared value indicates the high accuracy of the exponential equation at predicting future emission values. Furthermore, Table 3 shows the calculated average energy use per kilometer distance travelled for EV users that partook in the study. This was used for comparison of the estimate energy use per kilometer efficiency estimated from published EV energy efficiencies to provide relative confidence in the data obtained from interviewees.

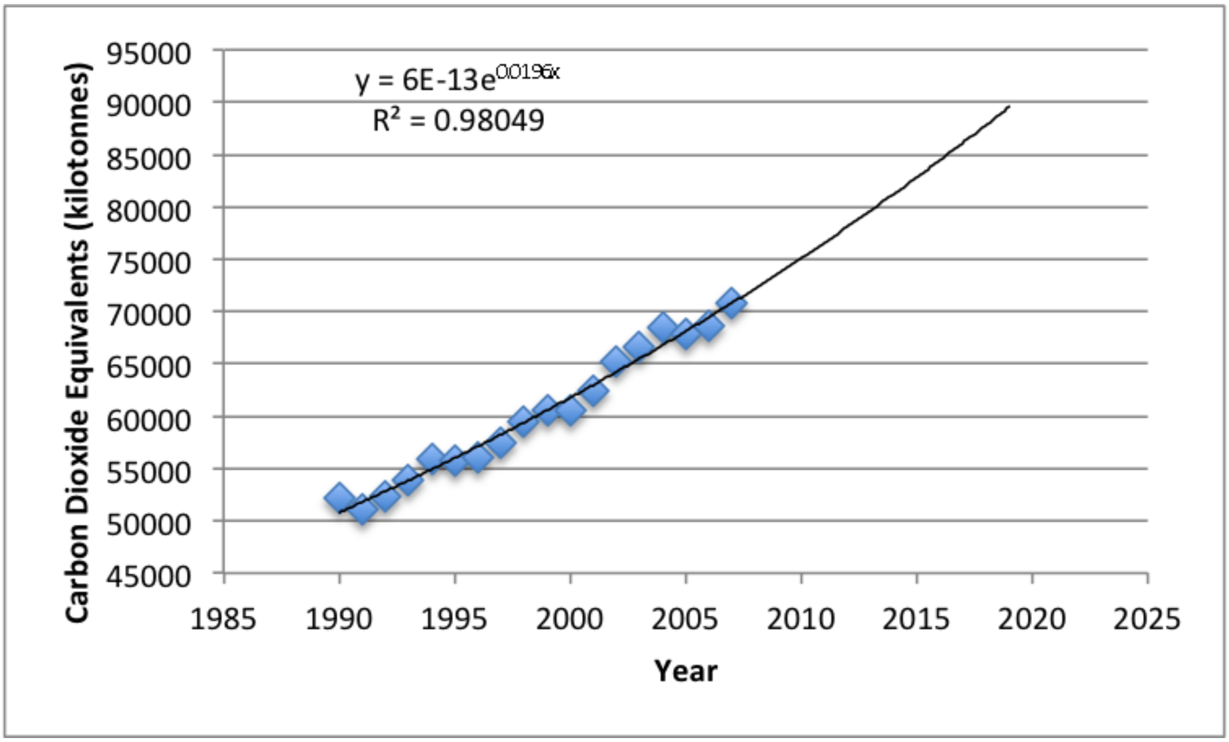

Figure 3: Exponential growth of CO_2e (kilotonnes) emissions from households' privately owned vehicles in Canada from 1990 to 2007, forecasted to 2020, using data obtained from Statistics Canada on June 17, 2013.

Table 3: Average energy used in one year (kWh), distance travelled in one year (km), and energy use per kilometer (kWh/km) calculated from data obtained from 15 electric vehicle (EV) owners and average of published efficiency ratings of EVs available in Canada and an average travel distance of 20,000 km annually, June 17, 2013.

Source	Average Energy Used In One year (kWh)	Distance Travelled In One Year (km)	Energy Use Per Kilometer (kWh/km)
Interviewees	2,600	14,092	0.18
Estimation from published efficiency ratings	4,042	20,000	0.20

5.1.2 Mitigation of Electrical Energy Demand by PV4EV Users

Data was limited with respect to interviewees who were currently using PV to offset their energy requirements for their EV. Of those that were using these systems, long-term data was largely unavailable. However, it was demonstrated by at least one participant that an average PV system is capable of offsetting the energy required to power an EV. Furthermore, the addition of a PV system to any building where an EV may be charged has the potential to contribute to mitigating electric energy consumed. As previously mentioned in section 1.7.2, PVs may account for between 10-30% of an average household's energy needs. This could be significant in a city such as Colwood who has seen population growth of nearly 10% over the last decade.

6.0 Discussion

Further exploration of the comparison of the estimated GHG reductions from implementing PV systems for electric vehicles to the emissions reductions determined from real users is discussed in the following sections. Also discussed are details regarding transitioning from a reliance on grid-tied energy to self-sufficient energy production, through the use of PVs. This includes the benefits and barriers associated with PV4EV, and the impacts at the community level. The implications of addressing the ever-increasing demand for electricity through the development of future hydroelectric infrastructure are also considered.

6.1 Carbon Emissions from Electricity Generation

In 2010, BC Hydro reported that 20 to 30 tCO_2e is generated per GWh, which equates to 0.02 to 0.03 $kgCO_2e$ per kWh (BC Hydro, 2012). Based on these numbers, it can be estimated that if 2600 kWh is used on average by real EV users, 52 to 78 $kgCO_2e$ per year is attributable to charging one EV using grid-tied electricity. Similarly, 520 kg to 780 $kgCO_2e$ per ten EVs. According to the LEV worksheet, for every ten EVs, 486 to 729 kg of CO_2e would be generated for every ten EVs using on-grid electricity giving a combined range of 486 to 780 kg CO_2e emissions per ten EVs per year. Projected growth statistics indicate that many more vehicles will be on the road, some of which are likely to be EVs. As more EVs are driven, there will be an increase in electricity consumption, and thus CO_2e emissions from power production facilities much like BC Hydro. Upon considering the emissions generated throughout the life cycle of a PV system, switching from on-grid electricity to solar does not appear to significantly mitigate CO_2e emissions.

6.1.1 GHG Emissions Reduction

By supplementing EVs with PV, the associated emissions from on-grid electricity generation can be avoided entirely if the emissions from manufacturing PV are not considered. The estimated annual energy requirement to offset an EV was found to be much higher (4042 kWh) than what was found to actually be used by our interviewees (2600 kWh), suggesting greater effectiveness of a PV for EV system. This can be explained by two things; less annual travel distance and better vehicle efficiency. We found that on average, the EV users who were interviewed drove 14092 km per year, rather than the 20000 km obtained from Stats Canada used to make the estimation, thus consuming less energy. We had estimated that based on the average energy efficiency of all subcompact EVs available in Canada, supplemented with a typical solar array including six, 250 W solar panels and five hours of sunlight per day, that 3000 W could be generated annually and that 0.20 kWh would be consumed per kilometer driven. From the data collected, we found that EV users were actually obtaining efficiency closer to 0.18 kWh/km. By utilizing photovoltaics to offset the energy consumed by an EV, CO_2e emissions from personal transport are virtually eliminated.

6.1.2 From On-grid to Off-grid

It is an interesting paradigm that society in North America large seems to value mass-production and mass-consumption. With the supply of resources decreasing and population increasing, it is important for society to being to shift to one of conservation and local production to ensure a sustainable and resilient livelihood. The electrical grid system we have today depends on huge infrastructure, and large corporations to finance the development and produce the energy, which we are forced to buy from them as a commodity. Energy is widely available in our environment, and PV technology is one example of how we can harness energy from the sun. Society needs to be aware that many small energy-producing technologies can be more effective and less degradative of our environment than these large mass-producing facilities we have today.

6.1.3 GHGs Produced from Manufacturing PV

A review was published in 2012, and it considered and harmonized the findings of five out of 109 reviewed studies that looked at the GHG emissions produced during the life cycle of PV systems. The studies considered PVs manufactured using amorphous silicon (a-Si), cadmium telluride (CdTe), and copper indium gallium diselenide (CIGS). Under normal conditions, (2,400 kWh/m^2/year irradiation, a performance ratio of 0.8, and a 30 year lifetime), it would be expected that 21, 14, and 27 g of CO_2e per kWh that is generated for a Si, CdTe, and CIGS technology, respectively (Kim, Fthenakis, Choi, & Turney, 2012). Other significant emissions associated with the PVs come from the mining processes of the metals involved in the manufacturing process. More details are provided in section 6.5. If a range of 0.014 to 0.027 kg CO_2e is produced per kWh, and if we consider from the research that on average, EV users consume approximately 2600 kWh annually, a total of 36.4 to 70.2 kgCO_2e could be attributable to a functioning PV array, given the conditions previously specified. This falls in the range of the expected emission reductions (48.6 to 78.0 kgCO_2e/PV4EV) from using a typical PV system to offset an EV, rather than BC Hydro's services. Additionally, it may be a low estimate for the amount of energy required to offset an EV (2,400 kWh/m^2/year irradiation), which is higher than the conditions set forth for the measurement. Using emissions only, transitioning from on-grid to off-grid does not reduce a significant proportion of generated CO_2e emissions. Also, the energy payback time for typical PV is reported to be 1.3 to 6.1 years (Kim *et al*., 2012). During this time, emissions savings from having installed the PV could be considered to be offsetting the production of the technology itself. With that said, the remaining 25 years of its life cycle could be spent offsetting emissions elsewhere.

6.2 Emissions from EVs

There is a major assumption that EVs are emissions free. Although they do not produce tail pipe GHG emissions, they are still responsible for a portion of the emissions generated from the energy production required to power them (Wilson, 2013; Doucette & McCulloch, 2011). The carbon intensity of the electricity obtained from the grid varies from country to country, as it depends on the proportions of coal, oil, natural gas, nuclear, and renewable resources used to generate electricity. Canada's electricity generation has low carbon intensity, as a large percentage of its energy comes from hydroelectric dams. Many governments have used EVs to reduce the CO_2e emissions and reduce their dependency on oil. However, the effectiveness of reducing emissions through the use of EVs depends on where and how they are charged (Wilson, 2013). According to Wilson (2013), 80% of global emissions from the grid come from direct fuel combustion and 10% are generated from the indirect fuel production. These emissions include CO_2, N_2O, and CH_4 from fuel extraction, transportation, processing, distribution, and storage. An additional 10% comes from losses in transmission and distribution (Wilson, 2013). When calculating emissions, it was assumed that the performance efficiency of an EV was 0.211kWh/km, equivalent to the US EPA rating of the Nissan Leaf (Wilson, 2013).

When determining the total emissions associated with EVs, emissions from the manufacturing process must also be considered. Wilson (2013) estimated that manufacturing emissions for an EV was 70 gCO_2e/km; this is based on an EV with a 24kWh battery, lifetime mileage of 150,000 km, as well as a performance efficiency of 0.211kWh/km (Wilson, 2013). The total EV manufacturing footprint was 10.5tCO_2e and from that, four tonnes comes from battery manufacturing (Wilson, 2013). In addition, several life cycle assessments have determined EV manufacturing emissions in the range of 50-90gCO_2e/km given a lifetime mileage of 150,000 km (Wilson, 2013). This estimate is approximately 60% higher than the manufacturing emissions of ICEs, which will generate almost 40gCO_2e/km (Wilson 2013).

6.3 BC's Current Energy

An analysis of the source and resiliency of BC's current energy supply and issues surrounding the environmental and social impacts of hydroelectricity was completed. The following sections will identify and explain the findings as well as address how PVs could be used to help mitigate some of these issues.

6.3.1 Sources and Resiliency of BC's Electricity

In BC, approximately 90% of electricity is generated by hydroelectric means (BC Hydro, 2013b). In 2012, BC Hydro produced approximately 50,000GWh, which is around 560,000 tCO_2e, or roughly 11.2 tonnes CO_2 per GWh (BC Hydro, 2012). In 2011, 1,074,000tCO_2e were emitted. It has been reported that between 20 to 30 tonnes CO_2 per GWh is generated year to year by BC Hydro and its Independent Power Producers. This is significantly lower than other Canadian coal-fired generation, which ranges from 800 to 1000t CO_2 e per GWh, and is due to the high use of hydroelectricity in BC (BC Hydro, 2012). In 2006, the CRD predicted a population growth rate of 36% over the next 30 years (Capital Region District, 2008). Considering the potential requirement of 1700 GWh to supply projected growth, the increase in GHG emissions would equate to approximately 34,000 to 51,000tCO_2e every year by 2036. As the population of BC grows in size, electricity demand will also increase. This will likely lead to the development of new hydroelectric dams, such as Site C, run of river systems, or further burning of fossils fuels to generate enough supply to meet the demand. Also, as mentioned previously, 83% of all households in BC owned or leased at least one vehicle as of 2006, and in Victoria, 64% of the population travelled to work by single occupancy vehicles, a third of which commuted more than 20 kilometers (Statistics Canada, 2006). If people begin to purchase EVs rather than ICE vehicles, the energy required to charge these vehicles will add further strain to the growing electricity demand. One option to help mitigate some of this demand is to invest in solar technology. A typical six panel, 250-watt solar array could produce around 3000 kWh annually, and using the fuel economy of EVs currently available in Canada, it can be estimated that at least 75%, of the energy needed to offset an EV completely, could be achieved. Also, with a typical six panel, 250-watt solar array and an average of five hours of sunlight per day, approximately 3000 kWhs can be produced per year, creating a 10% reduction in household energy costs when the PV4EV system is not being used to charge an EV. As mentioned earlier, through this project it has been estimated that for every ten PV4EV installations within the City of Colwood, 35.14 to 35.38 tCO_2e emissions per year could be avoided. Therefore, the use of PV4EV could not only offset electrical demand, but also has the potential to reduce significant amounts of GHGs if used on a larger scale. The use of only 60 PV4EV could offset the entire 2012 corporate carbon emissions of the City of Colwood. The possibilities are vast if PV4EV were implemented on a much larger scale. The use of EVs has the potential to significantly offset transportation emissions by replacing combustion engine vehicles. Further reduction of emissions from electricity generation could occur through partnership with photovoltaic technology.

As mentioned previously, Vancouver Island is only able to produce 30% of its electricity requirements, and this value is expected to decline as the population increases, since both energy demand and population are inextricably linked. As the current system of undersea cabling is used to deliver energy from the mainland reaches the end of its useable life, the resiliency of electricity on Vancouver Island will become questionable (The Greater Victoria Chamber of Commerce, n.d.; Whiticar, 2012). The resiliency of BC’s electricity will also be impacted greatly in the future by climate change and the resulting changes in water availability. In Canada, it is expected that overall precipitation will increase due to global climate change; however, it will occur in fewer, but more extreme events, with an increased risk of flooding (Weaver, 2008). Also, there will be increases in the length of periods with little to no precipitation, and summer drought will become more common (Weaver, 2008). Warming in the western mountains will also lead to reduced snowpack, causing more winter flooding and decreases in summer flows (Weaver, 2008). From these projections, it can clearly be seen that there will be significant water storage issues, in terms of having enough water at the right time, to maintain sufficient flow to generate hydroelectricity throughout the year. Between the expected increase in population and electricity demand, the questionable resiliency of undersea cabling that brings energy to Vancouver Island, and projected climate change impacts on water storage for hydroelectricity, it is obvious that there are significant concerns with BC and the CRD's current energy supply. The use of alternative energy sources, such as wind, geothermal, and PV provide a possibility for mitigating some of these concerns.

6.3.2 Impacts of Hydroelectric Generation

In 2012, the population of BC was 4,615,000 and is expected to grow to around 5,941,000 by 2036 (Government of BC, 2012). With increased population will come an increase in demand for electricity. This is evident by the proposition of the Site C dam, as BC Hydro predicts the need for the increasing electricity as the population grows. This project will produce approximately 5100GWh/year (BC Hydro, 2013b). Considering that there is the potential requirement of 1700GWh to supply development by 2036 within the CRD alone, the Site C dam will not provide a significantly large amount of extra energy required to meet demand throughout all of the province (Capital Region District, 2008). At a financial cost of around $7.9 billion, as well as numerous significant environmental and social costs, the obvious question is whether BC should be utilizing more alternative energy sources, as the City of Colwood is currently doing (BC Hydro, 2013b). Environmental impacts on the hydrological system and river dynamics; on physico-chemical cycles; on soil, surface water and groundwater quality, and environmental toxicity, or on ecosystems need to be considered with the use of hydroelectricity (Wildi, 2010). Also, ecosystem impacts can include the loss of forests and wildlife habitat, loss of populations, degradation of upstream and downstream habitat, loss of aquatic biodiversity, loss of fisheries, and a loss of ecosystem services from floodplains, wetlands, riverine, estuary, and adjacent marine ecosystems (Wildi, 2010). Water retention also leads to decreased recharge of wetlands, groundwater, and surface waters (WWF, 2004). The Site C dam specifically has significant environmental and social impacts. The transformation of the river ecosystems is expected to result in impacts to, and the loss of, many species (BC Hydro, 2013b). Furthermore, significant social costs will result from the construction of the Site C dam (BC Hydro, 2013b).

GHG emission reductions, impacts from hydroelectricity, and energy security, are three issues that new technologies, such as PV4EV may help to mitigate. Electricity can be produced from a renewable resource, and transportation can essentially become emission free. Through the incorporation of PV4EV into a residential household, future electricity demand may be mitigated greatly. This will also help to minimize the costs of ecosystem loss and degradation, financial costs, and societal impacts associated with building and operating more hydroelectric generation stations, and the burning of more fossil fuels for energy.

6.4 Cost Analysis of a PV System

Renewable, emission-free solar energy used to power EVs seems like a good idea, as long as the actual PV systems capturing this energy are sustainable and cost-effective themselves. There are numerous companies that install solar panels, sell solar panels, or build solar panels, so an exact cost of a PV system will vary depending on the specific choices of the buyer. Home Energy Solutions (HES), a company that designs, sells, and installs solar panel systems in the Victoria area, has established a PV system design for charging a typical Nissan Leaf EV based on their own calculations.

To determine the payback of a PV system after its purchase, the driving distance and the efficiency of the EV must be considered. Nissan provides estimates for the Leaf's energy usage to be 0.15 kWh/km, and the average annual driving distance per year for BC residents to be 13,100 km, creating a 1965 kWh/year annual energy usage (HES PV, 2013b). These are very similar to the values from Table 3. From the interviewees, the average EV energy usage is 0.18 kWh/km, average annual driving distance per year is 14,092 km, with a 2600 kWh/year annual energy usage. The design of the PV4EV system can also involve many variables, and may have enough panels to provide for all of the EV's electricity use, a partial amount of the electricity required to power the EV, or more than enough electricity to power the EV, after which surplus electricity can be used in the house. Cost is usually a factor in determining the number of panels a buyer will have installed on their house, but the array of panels can be expanded or altered at any time.

HES uses various PV systems, but the HES MicroBLOX kits are recommended for being compact and easy to install. Each MicroBLOX kit is calculated to output approximately 542 kWh of electricity, or enough electricity to power an EV to drive a distance of 3613 km/year (HES PV, 2013b). For the average BC driver, four MicroBLOX kits would be required; each kit contains 8- 235-watt solar panels, eight inverters, wiring and solar panel racking to complete installation (HES PV, 2013b). Previous installations completed by HES in Colwood began with a base cost of $2000 for the main hook up and running wiring to the roof of the house, and each MicroBlox installed costs $2000 (Ed Knaggs, personal communication, July 2, 2013). The EV charging unit, (consisting of the plug-in box and monitor), which is connected to the grid, costs approximately $800, with a $300 installation price (Victoria Leaf Club, 2012). LiveSmartBC currently has a rebate program in effect for up to $500 per eligible EV charging station, which is a part of the Clean Energy Vehicle Program point of sale incentives (Province of BC, 2013). Solar Colwood also has some options available for rebates for EV home charging stations. For a Level 2 charging station powered by PV, Solar Colwood may provide a rebate for up to 33% of the total cost of an eligible system, up to a maximum of $4000 (City of Colwood, 2013).

The price of a PV4EV system is not cheap; however, they have quite a long lifespan. HES estimates the MicroBlox product life to be 30 years, and they provide a 25-year warranty on the panels and inverters (HES PV, 2013a). Not considering all the factors, it is possible to do a quick comparison between paying for gasoline for 25 years for a combustion engine vehicle versus paying for the installation of a PV system for an EV and not paying for any gasoline for 25 years by running on solar power. A typical 2013 Honda Civic car averages 13.6 km/L (US EPA, 2013), and gasoline as of July 2013 was priced at $1.35/litre of fuel. A person who drives 13,000 km per year in their EV would require a PV4EV system with a total cost of approximately $10,000, which would power an EV for 25 years. A Honda Civic driver would spend approximately $1,300 per year on gasoline, which would equate to approximately $32,000 in fuel alone, over 25 years. This is a very basic comparison; however, it illustrates that a PV system is actually quite cost-effective in the long term.

6.4.1 Are Solar Panels Becoming Less Expensive?

As the availability of fossil fuels decreases and costs increase, alternative fuel sources will become more available, technology will improve, and electricity sources such as PVs will decrease in price. PV is a relatively new technology, and it is currently experiencing exponential growth (World Bank, 2010). Although the economy is dynamic and influenced by many factors, the price of PVs will depend on demand. As the technology is still developing, there is ample room for improving the efficiency of the technology, methodologies, and business models (CEEP, 2010). In contrast, fossil fuel technology futures are more limited.

PV installations are becoming increasingly more popular, with applications for both on- and off-grid uses. In Colwood, there have been five PV installations in the past 16 months (Judith Cullington, personal communication, July 4, 2013. According to HES, from 2008 to 2013, the price of solar panels has decreased by 75% (HES PV, 2013a), while the Center for Energy and Environmental Policy estimates the reduction of PV costs in the last two decades to be over 80% (CEEP, 2010). The greatest contributor to the cost of a PV module is the cost of polysilicon, with the next being the inverter, and other costs including labour and additional components of the system (CEEP, 2010).

A contributor to the decline in the price of solar panels, in addition to changing technology and efficiency, is the availability of panel supply. Panel prices declined by as much as 30% in 2012 due to oversupply of inventory to the market and decline in production costs (Forbes, 2013). Availability also depends on imports and exports of products and raw materials for manufacturing, which are regulated by government. But as solar power becomes increasingly known and preferred, PV panels will become more available to a wider range of consumers, and PV4EV use may increase as well.

6.4.2 Is BC's Energy Less Expensive than PV?

Although, information is available about both the costs of the Province's current energy (BC Hydro) and the cost of PV systems, it is difficult to provide an answer to whether BC's energy is less expensive than PV. In the timeframe of this project, it was not possible to compare the costs of the two sources of electricity in detail. It is necessary to consider the indirect costs, such as the cost of each type of energy, and the impacts they have on the environment, as well as the natural resources used in their production.

6.4.3 Are EV Prices Decreasing?

The initial cost of an EV is between $4,000 and $13,000 more than its ICE equivalent (Moorhouse & Laufenberg 2010). This is due to the Li-ion battery, which can comprise almost half of the vehicle's production costs (Tsang *et al.*, 2012). The cost of a Li-ion battery in 2013 has been estimated to be $16,000 and is expected to decrease to $10,000 in 2015, and $5,000 in 2020 (Moorhouse & Laufenberg 2010). Since batteries are the most expensive component of EVs, this will reduce the cost of purchasing an EV significantly.

6.4.4 What is the Projected Growth of EV Sales?

Since the introduction of EVs into the mainstream automobile market, they have only made up around 0.1% of new car sales in Canada (Kilppenstein, 2013). There has yet to be an official release of new vehicle, or total electric vehicle sales from BC. Prior to 2008 there were virtually no battery-powered EVs, while 50,000 to 100,000 plug-in hybrid EVs comprised 0.5% of the total number of vehicles on the road in Canada (Government of Canada, n.d.). According to a report released by the Government of Canada (n.d), it was projected that by 2018 there will be approximately 500,000 highway-capable plug-in EVs, and an even greater number of plug-in hybrid EVs. However, a more recent report by Hurst (2012) forecasted that annual EV sales in Canada would reach 107,146 by 2020, which is only 26% of the United States forecast of 400,073 EV sales per year. Per capita, this equates to 1 EV for every 322 people in Canada and 1 EV for everyone 78 people in the US. Ontario, Quebec, and BC are currently the only provinces in Canada that offer rebates for purchasing LEVs. Therefore, these provinces represent 97% of EV sales in Canada by 2020 (Hurst, 2012).

6.6 Barriers

6.6.1 Limited range

The limited range of EVs has been identified as one of the major barriers for its acceptance in the automobile market. A Nissan Leaf with a 24kWh battery has a range of about 100 km; however, this is considerably less than its ICE counterpart (Electric Vehicle Initiative, 2013). Other EVs use larger batteries and offer a greater driving range, such as the Tesla Model S, which can travel up to 480 km; it comes with a much higher retail price, which may dissuade most consumers (Electric Vehicle Initiative, 2013). An EV trial introduced several EVs as fleet vehicles in order to examine vehicle performance in real life scenarios (Tsang *et al*., 2012). The results revealed that the drivers of EVs tended to be more conservative when planning trips. The longest trip was only a quarter of the average vehicle range, and almost all of the trips (93%) involved a battery that remained at least 50% charged after completion (Tsang *et al.*, 2012). Even when considering the range of the Nissan Leaf, the range is adequate for daily commutes from home to work. In Canada, almost 90% of the population travels less than 60 km per day in round trips to and from work (Electric Mobility Canada 2010). Furthermore, 59% of Canadians live less than 10 km from their work (Electric Mobility Canada, 2010).

6.6.2 Slow Charging Versus Fast Charging

The time required to recharge EVs is another major barrier to the greater adoption of EVs, as consumers would be less likely to purchase one because of the refuelling convenience of an ICE counterpart. On average it can take 6 to 8 hours, using a Level 2 charging system, although it may take longer depending on the size of battery and model of electric vehicle (Tsang *et al*., 2009). The most commonly used recharging stations are Level 1 or Level 2, which are typically used for overnight charging or as backup systems. Level 1 uses a 125 VAC branch circuit, which is the lowest and most common voltage level for commercial and residential buildings, and has an amp rating of 15 or 20 amps (BC Hydro, 2009). Due to the widespread use of 125-volt systems, it is the most used systems for EV conversions (BC Hydro, 2009). The preferred method for charging is a Level 2 system, which has a 240 VAC single-phase branch circuit, and the connector allows for the current to reach up to 80 amps, although it usually has a rating of 40 amps AC and provides up to 7.7kW (BC Hydro, 2009). Level 3 charging is intended to perform similarly to a gasoline service station, in that it will recharge at least 50% of the battery in less than 15 minutes (BC Hydro, 2009). However, Level 3 charging stations are still relatively expensive and several models of EVs are not equipped to use fast charging systems.

6.6.3 High Cost of Batteries

The high cost of the battery also deters many people from purchasing an EV, since this component can comprise almost half of the EV's costs (Tsang *et al.*, 2012). The conversion from lead acid to lithium-ion batteries has reduced costs, but in order for production to become more economical, technological improvements are required (Tsang *et al.*, 2012). According to Axsen *et al*. (2010), the battery cost was one of the most important aspects of the five performance goals for EV batteries, i.e., power, energy capacity, life span, cost, and safety, affecting the greater adoption of EVs. The cost of Li-ion batteries is decreasing, and has almost by halved in the last four years (Electric Vehicles Initiative, 2013). Battery production costs went from USD $1,000 per kWh in 2008 to USD $485 per kWh in 2012 (Electric Vehicles Initiative, 2013).

6.7 Community Impacts

As solar technology advances and communities are developed, re-developed, and based around master plans, there is great potential for the use of PV to mitigate the need to generate electricity and transmit it long distances. By municipalities encouraging and sustainable energy projects, peoples behaviours may change as they become increasingly aware of their own carbon footprint, and the cost is has to them, their community, and the environment. By being a leader in alternative GHG emission reductions, via projects such as PV4EV and Solar Colwood, the City of Colwood is setting an example for neighbouring municipalities. They are demonstrating that such installations and technologies are not risky investments, but practical and intelligent support of responsible infrastructure that will eventually become a part of the "norm". This support can also lead to economic advantages when local businesses partner with local governments, such as occurred with the Royal Bay Bakery in Colwood. Such partnerships enable local government to encourage businesses that are committed to sustainability and also help to bring recognition to businesses that are taking steps to better the community.

By creating projects such as Solar Colwood, local governments are able to encourage community-based projects that can have large-scale benefits. Even if federal or provincial governments do not offer such opportunities, by developing local projects, the municipal government is encouraging community involvement and a sense of collective accomplishment by its citizens. Bioregional and local initiatives provide an appropriate scale for meeting human needs, developing partnerships between consumers and producers, and enable people to exercise their civic responsibility (Newman & Jennings, 2008). Furthermore, cooperative partnerships between communities, governments, and businesses, such as those that produce PV panels, encourage citizen empowerment and a desire to preserve the community they are part of (Newman & Jennings, 2008). Local government initiatives also encourage a sense of place in their citizens. This leads to people developing connections with their bioregion and a feeling of belonging to a home-place or life-place that includes the city they live in (Newman & Jennings, 2008). This not only inspires a sense of community and a desire to preserve and protect this community, but also encourages sustainability.

As community members begin to make the switch from complete reliance on on-grid electricity to becoming producers of electricity, they are likely to catch the attention of others. Many people seem to have an interest or express curiosity about alternative energies, including the potential of solar technology, and electric vehicles. These topics can encourage community engagement as individuals start to question their impact on the environment, and may affect how and where they invest their resources, as they witness neighbours using alternative technologies to meet their long-term energy needs. Individuals can also gain a sense of belonging to a certain community group by functioning a role model and being an example setter. Clubs and groups such as the Nissan Leaf Club and the Vancouver Electric Vehicle Association are living examples of this effect where individuals who share common values have come together.

6.7.1 Encourages Sustainability

PV4EV systems offer other additional benefits to individuals and families. One primary benefit that people often rarely consider is the resiliency and security that such a system can offer to the household. In times of emergency or disaster, a PV system can continue to provide electricity to meet the basic needs of people, such as powering a refrigerator, radio, or computers. The EV adds the capacity of being able to store additional electricity in its battery when it is not needed, which through proper system design and engineering, could then be utilized as needed during the night, or during times of low light conditions. In master planned communities, a neighbourhood alone may have its own small grid, so that everyone is producing power and in times of excess, it can be utilized by other households in the neighbourhood. Similarly, if one home has a system failure, the systems of other homes can power the one home until it is repaired. This is of increasing importance of communities like the City of Colwood that reside in an earthquake zone, and on an island powered from the mainland.

PV systems encourage sustainability by reducing dependency on fossil fuel energy and even hydroelectricity, which come with significant environmental and social impacts. For a city to be truly sustainable, there needs to be a connection between production and consumption. Sustainable production requires the development of new ways of producing goods and services, with far fewer resources consumed and minimal to no waste (Newman & Jennings, 2008). While PV technology does have some issues associated with the production and decommissioning of its panels, it offers a much more sustainable solution for generating electricity. It does not require the use of non-renewable resources, and generates very little waste, much of which is recyclable. A key to reducing citizen consumption is to associate production and consumption together (Newman & Jennings, 2008). If people can see how their electricity is generated, and how much they are generating through data information on the PV systems, they may be more likely to become aware of how they are consuming electricity and take steps to conserve it.

6.7.2 Cleaner Living Environment

Reducing harmful emissions is beneficial for everyone. Every human in every community across the world has the fundamental right to clean air, and by utilizing renewable energy resources, and ones that do not generate much pollution post-manufacture, this right can be upheld. PV4EV has the potential to reduce urban air pollution issues such as smog and ground level ozone. It also has the potential to reduce noise pollution, as an EV is typically much quieter than a conventional ICE.

7.0 Conclusions and Future Directions/ Recommendations

In conclusion, this research has provided a clear depiction of the role that PV and EVs may play in mitigating future GHG emissions within the transportation sector. Such technologies will allow society to take the next step towards a sustainable and resilient future for generations to come. They will allow people the opportunity to become producers rather than consumers, while maintaining the ability to move around our environment efficiently, with a minimal ecological and carbon footprint. We have determined that even on a small scale (approximately 60 systems), PV4EV systems are a viable option for municipalities such as the City of Colwood to reach carbon neutrality, without the need for external spending on carbon offsets. However, upon looking at life cycle-related emissions over 30 years for a PV system, the GHGs produced by them is not significantly different than the emissions they directly offset with regard to an EV (46.8 to 78.0 Kg CO_2 annually per EV from BC Hydro and 36.4 to 70.2 Kg CO_2e annually per EV from PV). The GHGs associated with the lifecycle of a hydroelectric plant also need to be considered for a fair comparison. The difference in embodied CO_2e between the manufacturing of an EV and an ICE should also be determined for a complete and accurate comparison.

We recommend that incentives for these types of systems continue into the future to encourage individuals to rely less on fossil fuel for daily needs, such as transportation. The public awareness of these options needs to be greater and easy to access, and must include the complete cost-benefits of investing in a PV4EV system rather than an ICE vehicle. Also, it is recommended that municipalities work along side EV dealers for two reasons: to educate EV salespeople about the potential benefits of supplementing an EV with a PV; and to potentially include the cost of a PV system into the financing of an EV. It is crucial to the sales of EVs that car salespeople accurately express the long-term benefits of investing in an EV with or without PV, to ensure that they are not deterred merely by the upfront cost of an EV. Dealers should also be educated on the benefits of having a PV system tied into the home, for both the financial savings and self-sufficiency aspects. It may also prove to be easier to get people to supplement their EV with a PV if EV dealers were able to sell PV4EV packages under one finance plan. Dealerships should be encouraged to have a PV4EV demonstration system showcasing the options.

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Appendix A - Questionnaire for Interviewee

Hello, my name is _______, and I am conducting a research project, along with four other classmates, that is part of the requirements for a Bachelor of Science Degree at Royal Roads University. The objective of our research project is to determine Greenhouse Gas Emission reductions from the use of photovoltaic cells for electric vehicles for the City of Colwood. In addition to submitting my final report to Royal Roads University in partial fulfillment for a Bachelor of Science Degree, I will also be sharing my research findings with The City of Colwood. Findings will be presented publically in August 2013, as well as documented in a formal research report. We are looking for current users of electric vehicles (EV) to answer the following questions for our research:

- Type of EV currently owned
- Kilometers driven in one month or one year
- Proportion of highway vs. city driving
- kWh used to charge vehicle
- Previous vehicle or other internal combustion vehicle owned
- Is EV only vehicle you own
- If no, estimate of proportion of driving EV vs. combustion engine vehicle
- Barriers to owning a photovoltaic for charging electric vehicles

All information will be recorded in hand-written format and summarized where appropriate in the body of the final report. No personal details will be linked to information you share with me today and your identity will be kept anonymous within the report, unless agreed otherwise. At no time will any specific comments be attributed to any participant in the study unless specific agreement has been obtained beforehand. All documentation will be kept strictly confidential. Raw data will be kept in the final report retained by Royal Roads University and all other data will be destroyed upon completion of the project.

If you would like to participate in this study, please email your answers to ________ at name@royalroads.ca . By providing answers to this study, your email response is considered your consent to participate. You are not compelled to participate in this research project. If you choose not to participate, you are free to withdraw at any time without prejudice. Similarly, if you choose not to participate in this research project, this information will also be maintained in confidence.

Thank you very much for your assistance.

Appendix B - E-mail Survey

Question and Answer Form for Participants

Question	Answer
Type of Vehicle	
Previous vehicle owned	
Is EV only vehicle owned	
Odometer reading and over what time	
Proportion of city vs highway	
If own another vehicle, proportion of EV driving vs combustible	
kWh used to charge vehicle (if known)	
Interest in owning PV and barriers to owning PV	

Consent from Participant

____

(Name of Participant)

____

(Signature of Participant)

____

(Date)

Appendix C - LEV Sample Worksheet

Below is a sample of the low emissions vehicle (LEV) worksheet obtained from the BC Climate Action Toolkit that was used to calculate avoided CO_2e emissions achieved by replacing an internal combustion engine (ICE) vehicle with an electric vehicle (EV). The ICE was assumed to have a combined efficiency of 21 miles per gallon, and 20.2 kWh/100 km for the EV, as well as an annual driving distance of 20,000 km. Data obtained from EV users about their past ICE and current EV was entered into this worksheet to find actual CO_2e savings from 15 independent interviewees.

Project: **Low Emission Vehicles - DRAFT**
Option 1: **Published fuel consumption ratings (Preferred)**
BC City:
Participation:

Legend

(red box)	Data entered by user
bold	Calculated by the spreadsheet
Baseline	Corresponds to the conventional new vehicle scenario
Project	Corresponds to the low emission new vehicle

Option 1A: Distance-based calculation

Step 1: Determine fuel consumption rating for both city and highway driving

Sources to consult:
Natural Resources Canada
The Manufacturer
If fuel consumption ratings are unavailable or otherwise inappropriate, use Option 2.

	Fuel consumption rating - **CITY**				
	Gasoline (l/100km)	Diesel (l/100km)	Propane (l/100km)	Natural Gas (kg/100km)	Electricity (kWh/100km)
Baseline	11.2				
Project					20.2

	Fuel consumption rating - **HIGHWAY**				
	Gasoline (l/100km)	Diesel (l/100km)	Propane (l/100km)	Natural Gas (kg/100km)	Electricity (kWh/100km)
Baseline	11.2				
Project					20.2

Step 2: Estimate share of city driving

Share (%)	
City	Highway
80%	**20%**

	Combined city/highway fuel consumption rating				
	Gasoline (l/100km)	Diesel (l/100km)	Propane (l/100km)	Natural Gas (kg/100km)	Electricity (kWh/100km)
Baseline	**11.2**	**0.0**	**0.0**	**0.0**	**0.0**
Project	**0.0**	**0.0**	**0.0**	**0.0**	**20.2**

Step 3: Specify renewable fuel blends

	Blends (%)		Blended fuel required (l/100km)	
	Ethanol	Biodiesel	Gasoline	Diesel
Baseline	5%	4%	**11.4**	**0.0**
Project	10%	4%	**0.0**	**0.0**

Required Baselines in British Columbia under Legislation
Renewable and Low Carbon Fuel Requirements Regulation (RLCFR)

	Blends (%)	
	Ethanol	**Biodiesel**
Gasoline	**5%**	
Diesel		**4%**

Step 4: Calculate total fuel consumption and emissions intensity

	Total fuel consumption (/100km)						
	Gasoline (l)	Diesel (l)	Biodiesel (l)	Ethanol (l)	Propane (l)	Natural Gas (kg)	Electricity (kWh)
Baseline	**10.8**	**0.0**	**0.0**	**0.6**	**0.0**	**0.0**	**0.0**
Project	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**20.2**

	GHG emissions intensity (kg CO2e/100km)							
	Gasoline	Diesel	Biodiesel	Ethanol	Propane	Natural Gas	Electricity	Total
Baseline	**26.72**	**0.00**	**0.00**	**0.85**	**0.00**	**0.00**	**0.00**	**27.57**
Project	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.51**	**0.51**

Emission factors:	2.47 kg CO2e/l	3.01 kg CO2e/l	2.45 kg CO2e/l	1.49 kg CO2e/l	1.53 kg CO2e/l	3.03 kg CO2e/kg	0.03 kg CO2e / kWh

Step 5: Enter annual travel estimates and fleet size

Annual travel estimates		
Average distance per vehicle (km/yr)	Fleet size (number of vehicles)	Total distance travelled per year
20,000	10	**200,000**

Step 6: Calculate annual baseline and project GHG emissions

	GHG Emissions
	t CO2e/yr
Baseline	**55.15**
Project	**1.01**

Step 7: Calculate annual avoided emissions

	Per vehicle	Total
	t CO2e/yr	t CO2e/yr
Emission Reduction CREDITS:	**5.41**	**54.14**

Appendix D - Raw Data Collected From Interview Participants

Participant 1
Type of EV currently owned:
1998 Cavalier conversion
Previous or currently owned ICE vehicle:
2008 Cavalier
Odometer reading per specific time period (e.g. km/month or km/year):
13000 km/6 months
Proportion of city versus highway driving (%):
10 to 90
Proportion of driving EV versus ICE [if still own one (%)]:
98 to 2
Average kWh used to charge EV:
8.6
Barriers to owning PV4EV:
Cost

Participant 2
Type of EV currently owned:
2012 Nissan Leaf
Previous or currently owned ICE vehicle:
**2000 Subaru Forester*
Odometer reading per specific time period (e.g. km/month or km/year):
923.6 km/month x 6 months
Proportion of city versus highway driving (%):
100
Proportion of driving EV versus ICE [if still own one (%)]:
50 to 50
Average kWh used to charge EV:
142.5/month
Barriers to owning PV4EV:
Rents house
**Year assumed as not provided*

Participant 3
Type of EV currently owned:
2012 Chevrolet Volt
Previous or currently owned ICE vehicle:
1985 Oldsmobile Cutlass Supreme
Odometer reading per specific time period (e.g. km/month or km/year):
1200/month
Proportion of city versus highway driving (%):
100
Proportion of driving EV versus ICE [if still own one (%)]:
100
Average kWh used to charge EV:
300/month
Barriers to owning PV4EV:
Costs and unknown lifecycle of batteries

Participant 4
Type of EV currently owned:
2012 Nissan Leaf
Previous or currently owned ICE vehicle:
**2000 Dodge Grand Caravan*
Odometer reading per specific time period (e.g. km/month or km/year):
**Unknown – not provided, assumed to be 20000 km/year*
Proportion of city versus highway driving (%):
100
Proportion of driving EV versus ICE [if still own one (%)]:
90
Average kWh used to charge EV:
Unknown – not provided, assumed average kWh for Nissan Leaf of 1/7 km
Barriers to owning PV4EV:
Unknown – not provided
**Year, odometer reading, and kWh used to charge assumed as not provided*

Participant 5
Type of EV currently owned:
2012 Nissan Leaf
Previous or currently owned ICE vehicle:
**Unknown - not provided, assumed Statistics Canada Average of 21mpg*
Odometer reading per specific time period (e.g. km/month or km/year):
1000/month
Proportion of city versus highway driving (%):
90 to 10
Proportion of driving EV versus ICE [if still own one (%)]:
100
Average kWh used to charge EV:
1/6.3 km
Barriers to owning PV4EV:
Cost
**Previous vehicle assumed as 21mpg using Statistics Canada average as not provided*

Participant 6
Type of EV currently owned:
2012 Nissan Leaf
Previous or currently owned ICE vehicle:
1995 Ford Escort
Odometer reading per specific time period (e.g. km/month or km/year):
6000/year
Proportion of city versus highway driving (%):
70 to 30
Proportion of driving EV versus ICE [if still own one (%)]:
100
Average kWh used to charge EV:
1/7 km
Barriers to owning PV4EV:
Roof orientation and tree cover

Participant 7
Type of EV currently owned:
2012 Nissan Leaf
Previous or currently owned ICE vehicle:
2011 Ford Fiesta
Odometer reading per specific time period (e.g. km/month or km/year):
2000/month
Proportion of city versus highway driving (%):
75 to 25
Proportion of driving EV versus ICE [if still own one (%)]:
98 to 2
Average kWh used to charge EV:
Unknown, increase of $50/month on hydro bill
Barriers to owning PV4EV:
Unsure if allowed to in neighborhood

Participant 8
Type of EV currently owned:
2012 Prius plug-in
Previous or currently owned ICE vehicle:
1992 Nissan Sentra
Odometer reading per specific time period (e.g. km/month or km/year):
10000/year
Proportion of city versus highway driving (%):
90 to 10
Proportion of driving EV versus ICE [if still own one (%)]:
100
Average kWh used to charge EV:
Battery capacity of 4.4kWh
Barriers to owning PV4EV:
Rents house

Participant 9
Type of EV currently owned:
2012 Nissan Leaf
Previous or currently owned ICE vehicle:
2000 Honda CRV
Odometer reading per specific time period (e.g. km/month or km/year):
1300/month
Proportion of city versus highway driving (%):
90 to 10
Proportion of driving EV versus ICE [if still own one (%)]:
95 to 5
Average kWh used to charge EV:
24kWh battery capacity charged to 80% daily
Barriers to owning PV4EV:
Weather and unsure if generates sufficient power in the winter

Participant 10
Type of EV currently owned:
2012 Nissan Leaf
Previous or currently owned ICE vehicle:
2005 Dodge Caravan
Odometer reading per specific time period (e.g. km/month or km/year):
30247/16 months
Proportion of city versus highway driving (%):
60 to 40
Proportion of driving EV versus ICE [if still own one (%)]:
70 to 30
Average kWh used to charge EV:
1/6.7 km
Barriers to owning PV4EV:
Cost

Participant 11
Type of EV currently owned:
1994 GMC Sonoma Conversion
Previous or currently owned ICE vehicle:
1997 Subaru Impreza
Odometer reading per specific time period (e.g. km/month or km/year):
5000/year
Proportion of city versus highway driving (%):
100
Proportion of driving EV versus ICE [if still own one (%)]:
33 to 67
Average kWh used to charge EV:
0.275/ km
Barriers to owning PV4EV:
Trees, weather, not parked at home during day, thinks government should do it

Participant 12
Type of EV currently owned:
2012 Nissan Leaf
Previous or currently owned ICE vehicle:
2001 Chevrolet Tracker
Odometer reading per specific time period (e.g. km/month or km/year):
1000/month
Proportion of city versus highway driving (%):
95 to 5
Proportion of driving EV versus ICE [if still own one (%)]:
98 to 2
Average kWh used to charge EV:
Unknown
Barriers to owning PV4EV:
BC low cost hydro, need to store extra energy

Participant 13
Type of EV currently owned:
2012 Nissan Leaf
Previous or currently owned ICE vehicle:
Honda Fit
Odometer reading per specific time period (e.g. km/month or km/year):
12000/year
Proportion of city versus highway driving (%):
80 to 20
Proportion of driving EV versus ICE [if still own one (%)]:
80 to 20
Average kWh used to charge EV:
1019.3/7370 km
Barriers to owning PV4EV:
None really, for others cost and shady roofs

Participant 14
Type of EV currently owned:
2012 Nissan Leaf
Previous or currently owned ICE vehicle:
2002 Honda Civic
Odometer reading per specific time period (e.g. km/month or km/year):
1400/month
Proportion of city versus highway driving (%):
80 to 20
Proportion of driving EV versus ICE [if still own one (%)]:
90 to 10
Average kWh used to charge EV:
210kWh/month
Barriers to owning PV4EV:
Cost, trees, and no buy-back from BC Hydro

Participant 15
Type of EV currently owned:
2012 Nissan Leaf
Previous or currently owned ICE vehicle:
2002 VW Beetle
Odometer reading per specific time period (e.g. km/month or km/year):
9800/year
Proportion of city versus highway driving (%):
80 to 20
Proportion of driving EV versus ICE [if still own one (%)]:
90 to 10
Average kWh used to charge EV:
1/7 km
Barriers to owning PV4EV:
None

Appendix E – Appendices 6 to 9 of the Becoming Carbon Neutral Framework, Sample Templates for Option 1 Projects

Appendix 6. Sample Project Plan Template (Option 1 Projects)

This form is also available online at http://www.toolkit.bc.ca/carbon-neutral-government. Local governments may choose alternate formats to the templates provided; however the substance must be the same as those provided in the sample templates.

Project Proponent Information	
Name of Local Government Project Proponent(s)	Provide the name of the local government(s) involved in the project and that will be claiming GHG reductions from the project under Option 1. ____
Project Designate appointed to sign off on Project Plan	Provide the name, phone and e-mail of the Project Designate duly authorized and having the legal capacity to sign off on this Template (e.g., CAO, CFO) Name____________________________________ Title ____________________________________ Phone________________ Email____________________
Project Contact	Provide a Project Contact name if different from above Name____________________________________ Title ____________________________________ Phone________________ Email____________________
Project Information	
Project title	Provide project title ____
Option 1 Project Profile	Confirm which Option 1 project and project profile you are implementing. Check only one per Project Plan Template submitted: ❑ Project 1A: Energy Efficient Building Retrofits and Fuel Switching ❑ Project 1B: Solar Thermal ❑ Project 1C: Household Organic Waste Composting ❑ Project 1D: Low Emission Vehicles
Project description and objectives	Briefly summarize the project in terms of what, where, how when and why (max 4-5 sentences or bullets).
Project co-benefits (Optional)	Beyond the reducing GHG emissions, describe any anticipated community and/or sustainability co-benefits that this project will provide (*e.g., energy cost savings, stimulation of the local economy through green job growth, foster technological innovation, raise public awareness of climate change / energy conservation)*
Project start date	Indicate the project start date:__________________________

Project Transparency: Accountability and Reporting	
Scope	❑ The Project Designate certifies that the project outlined in this Project Plan is outside of the scope of the local government's corporate emissions boundary as defined in the Carbon Neutral Workbook, as per the Project Eligibility Requirements outlined in Appendix 1 of the *Becoming Carbon Neutral* guidebook.
Counted Once	❑ The GHG reductions claimed from this project under the Carbon Neutral Framework have not been, and will not be, committed or sold as an emission reduction under any other alternate emission-offset scheme, as per the Project Eligibility Requirements outlined in Appendix 1 of the *Becoming Carbon Neutral* guidebook.
Ownership	❑ The local government proponent(s) claiming emission reductions from the Option 1 project outlined in this Project Plan have exclusive right to the GHG reductions that arise from the Option 1 project, as per the Project Eligibility Requirements outlined in Appendix 1 of the *Becoming Carbon Neutral* guidebook.
Verification	❑ The Project Designate understands that he / she will be required to sign off the annual Verification Template Report for this project to verify that the estimated GHG reductions from this project actually occurred during the year in which they will be claimed, as per the Project Eligibility Requirements outlined in Appendix 1 of the *Becoming Carbon Neutral* guidebook.
Reports	❑ The Project Designate, is aware of the public reporting requirements under the Climate Action Revenue Incentive Program (CARIP) and that after January 1, 2012, the CARIP reports will be revised to include information on total annual corporate emissions , the reductions being claimed from GHG projects undertaken under the Carbon Neutral Framework (Option 1 and 2) , and purchased offsets (Option 3) in order demonstrate carbon neutrality for any given year, as the Project Eligibility Requirements outlined in Appendix 1 of the *Becoming Carbon Neutral* guidebook.

Project Plan: Authorization and Sign Off

Project Designate

The information provided in this Project Plan, is to the best of my knowledge correct and complete.

______________________________________ ________________________

Designate Signature Date

____

Title

Appendix 7. Sample Self-Certification Template (Option 1 Projects)

This form is also available online at http://www.toolkit.bc.ca/carbon-neutral-government. Local governments may choose alternate formats to the templates provided; however the substance must be the same as those provided in the sample templates.

Project Proponent Information	
Name of Local Government Project Proponent(s)	Provide the name of the local government(s) involved in the project and claiming GHG reductions from the project described in this Template. ____
Project Designate appointed to sign off on the Self-Certification Template	Provide the name, phone and e-mail of the Project Designate duly authorized and having the legal capacity to sign off on this Template (e.g., CAO, CFO) Name____ Title ____ Phone______________________ Email__________________________
Project Contact	Provide a Project Contact name if different from above Name____ Title ____ Phone______________________Email__________________________
Project Information	
Project title	Provide project title and attach a copy of the original Project Plan previously made public. ____________________________________ ❑ Copy of Project Plan attached
Timing and Amount of reductions being claimed	Indicate the <u>amount</u> of GHG reductions, expressed in tonnes, being claimed from the project and the <u>timeframe</u> during which the emission reductions being claimed occurred. Amount of GHG reductions: __________ tonnes Timeframe: From __________ to ____________
Certification that the required work occurred	❑ I declare that the project work required to achieve the GHG reductions from this project as estimated by the project profile used, actually occurred during the year in which they are being claimed, as per as the Project Eligibility Requirements outlined in Appendix 1 of the *Becoming Carbon Neutral* guidebook.
Self Certification Template: Authorization and Sign off	
<u>Project Designate</u> *The information provided in this Self Certification Template is to the best of my knowledge correct and complete.* __________________________________ __________________ Designate Signature Date ________________________ Title	

Appendix 8. Sample Preliminary Review Template (Option 2 Projects)

This form is also available online at http://www.toolkit.bc.ca/carbon-neutral-government. Local governments may choose alternate formats to the templates provided; however the substance must be the same as those provided in the sample templates.

Project Proponent Information	
Name of Local Government Project Proponent(s)	Provide the name of the local government(s) involved in the project and that will be claiming GHG reductions from the project under Option 2. ____
Project Designate appointed to sign off on Project Plan	Provide the name, phone and e-mail of the Project Designate duly authorized and having the legal capacity to sign off on this Template (e.g., CAO, CFO) Name____ Title ____ Phone____________________ Email______________________
Project Contact	Provide a Project Contact name if different from above Name____ Title ____ Phone____________________ Email______________________
Project Information	
Project title	Provide project title ____
Project description and objectives	Briefly summarize the project in terms of what, where, how when and why (max 4-5 sentences or bullets).
Project Measurement	Describe the proposed approach to measuring the GHG reductions from the project. If available include detailed formulas, methodologies and assumptions and anticipated GHG reductions from the project.
Third party validation of formulas and methodologies	Identify who will provide third party validation of the proposed project formulas and methodologies (see Section 2.4.3 for a description of qualified third party validators) Name____ Title ____ Phone____________________ Email______________________