INTEGRATING WIND GENERATED ELECTRICITY WITH SPACE HEATING AND STORAGE BATTERIES

by

Anirudh Muralidhar

Submitted in partial fulfilment of the requirements
for the degree of Master of Applied Science

at

Dalhousie University
Halifax, Nova Scotia
December 2010

DALHOUSIE UNIVERSITY

DEPARTMENT OF ELECTRICAL AND COMPUTER ENGINEERING

The undersigned hereby certify that they have read and recommend to the Faculty of Graduate Studies for acceptance a thesis entitled “INTEGRATING WIND GENERATED ELECTRICITY WITH SPACE HEATING AND STORAGE BATTERIES” by Anirudh Muralidhar in partial fulfillment of the requirements for the degree of Master of Applied Science .

Dated: December 20, 2010

Supervisor: __________________________________

Readers: __________________________________

____

____

DALHOUSIE UNIVERSITY

DATE: December 20, 2010

AUTHOR: Anirudh Muralidhar

TITLE: INTEGRATING WIND GENERATED ELECTRICITY WITH SPACE HEATING AND STORAGE BATTERIES

DEPARTMENT OR SCHOOL: Department of Electrical and Computer Enginnering

DEGREE: MASc CONVOCATION: May YEAR: 2011

Permission is herewith granted to Dalhousie University to circulate and to have copied for non-commercial purposes, at its discretion, the above title upon the request of individuals or institutions. I understand that my thesis will be electronically available to the public.

The author reserves other publication rights, and neither the thesis nor extensive extracts from it may be printed or otherwise reproduced without the author's written permission.

The author attests that permission has been obtained for the use of any copyrighted material appearing in the thesis (other than the brief excerpts requiring only proper acknowledgement in scholarly writing), and that all such use is clearly acknowledged.

____
Signature of Author

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

ABSTRACT

The world faces two major energy-related challenges: reducing greenhouse-gas emissions and improving energy security. Wind-electricity, a clean and environmentally sustainable energy source, appears promising. However, its intermittency is problematic when used as a supply for on-demand electricity.

Wind-electricity can be used for space heating when combined with thermal-storage systems; although its intermittency can result in periods of excess electricity. To reduce the excess, this thesis proposes using wind-electricity for thermal-storage and electric-vehicles. Four charging procedures are designed and developed. Data from an eastern Canadian wind-farm is used to demonstrate the procedures.

The results are compared and discussed in terms of the supply of wind-electricity and its ability to meet the energy requirements of these services. Depending on the procedure, wind-electricity displaced between 20 and 26 GWh of energy previously required for space-heating and transportation, demonstrating that wind-electricity, with intermittently-chargeable loads using storage, is a solution to the intermittency problem.

LIST OF ABBREVIATIONS AND SYMBOLS USED

ETS	Electric Thermal Storage
PEVs	Plug-in Electric Vehicles
EVs	Electric Vehicles
CO_2	Carbon Dioxide
MW	Megawatt
MWh	Megawatt Hours
kW	Kilowatt
kWh	Kilowatt Hours
GW	Gigawatt
GWh	Gigawatt Hour
TOD	Time of Day
GSHP	Ground Source Heat Pump
DHW	District Hot Water
V2G	Vehicle to Grid
BOS	Boston
ROC	Rochester
PHL	Philadelphia
PHEVs	Plug-in Hybrid Electric Vehicles
PCIP	PHEV Charging Infrastructure Planning
ORNL	Oak Ridge National Laboratory

HDH	Heating Degree Hours
HVAC	Heating Ventilation and Air Conditioning
km	Kilometer
NS	Nova Scotia
PEI	Prince Edward Island
PEIEC	Prince Edward Island Energy Corporation

ACKNOWLEDGEMENTS

I owe my deepest gratitude to my supervisor; Dr. Larry Hughes for his guidance, encouragement, motivation, enthusiasm, knowledge and last but the least, the financial support without which this thesis would have be completed.

I am grateful to Dr. Jason Gu and Dr. Robert Bauer for accepting to serve on my supervisory committee and offering useful guidance for my thesis.

I am indebted in many ways to the members of Energy Research Group (current and former), Alain Joseph, Andrew Barnes, Dave Ron, Harisubramanian Lakshminarayanan, Jim Parsons, Jacinda Rudolph, Mandeep Dhaliwal, Nikhil Chowdry, Nikita Sheth, Shanmuga Sundaram, Tylor Woods, Vinay Kumar for their inputs during the course of my thesis.

I would like to thank Selina Cajolais and Nicole Smith who have made my stay in Dalhousie a pleasant and memorable one.

Finally, my parents and brother deserve special mention for their inseparable support and constant prayers which has been my constant guiding force through this thesis.

Chapter 1 INTRODUCTION

In the twenty-first century, the world will face two major energy-related challenges: reducing greenhouse gas emissions and improving energy security. Greenhouse gas emissions from the extensive use of fossil fuels are believed to be responsible for anthropogenic climate change (1) and ocean acidification (2). Energy security or "the uninterrupted physical availability at a price which is affordable, while respecting environment concerns" (3) is under threat in many jurisdictions because of the volatility of energy supplies and prices due to production challenges and increasing demand in China and other emerging market economies.

These above challenges are forcing some politicians and policymakers to reconsider the use of energy in their jurisdictions. In addition to reducing demand through conservation and energy efficiency measures, there can also be actions that are intended to replace existing energy sources that are insecure or environmentally damaging, or both, or restrict new demand to energy sources that are secure, environmentally benign, and preferably sustainable (4).

Electricity is an important part of our lives, almost everything we use right from lighting, cooling, electronic equipments such as laptops and cell phones run on electricity. As the demand for electricity keeps rising every year (5), coupled with concerns over the depletion and environmental impact of fossil energy sources, many countries are looking at alternatives and investing in cleaner and renewable technologies for the generation of electricity (6). A total of $155 billion was invested globally in sustainable energy sector in the year 2008 due to climate change, energy insecurity, fossil fuel depletion and the advancement of technologies. (6).

One energy source in particular that has caught the attention of both the public and politicians is wind-generated electricity, as it is a clean and environmentally sustainable energy source (6; 7; 8).

However, wind produces electricity intermittently, making it difficult to dispatch and integrate into a traditional electricity network (9). If wind is to make a significant contribution to meet the world's rising demand for electricity, it will be necessary to change the way it is consumed. Ideally, the electricity supplier has sufficient rapid-response electricity that can be brought on-line at short notice to handle those instances when it is necessary to "top-up" unexpected shortfalls in planned electricity supply or to find a consumer that will purchase the "spill" when there is more electricity being produced than expected. When shortfalls occur, it is necessary to have backup energy sources, such as hydroelectricity or gas-fired turbines to produce electricity rapidly (10). Alternatively, connecting to a large grid can offer backup when there is insufficient wind, potentially allowing sales of excess electricity, or simply being so large that any fluctuations in wind output are lost. For example, Denmark obtains about 20% of its electricity from wind, but this is only possible because the Nordic Electric Pool, Nordel, is used for backup; Denmark's wind is responsible for less than 2% of Nordel's total production (11).

In jurisdictions with limited access to backup or a significant grid structure to handle the intermittency of wind-generated electricity there are limited options: export the excess or limit the amount of wind that can be on the grid. However, this need not be the case, if one considers the different energy services available to most modern jurisdictions, notably transportation, heating and cooling, and a continuous supply of electricity (12).

For any northern country space heating is vital for human existence. If an intermittent source such as wind generated electricity can be used to satisfy the space heating demand, rather than using wind to replace a continuous source of energy, it can be looked towards satisfying loads such as space heating. Reviewing the residential sector of Canada, almost 63 percent of the energy required in 2007 was for space heating alone as shown in Table 1 , where about 25 percent of the space heating was met by electricity, as seen in Table 2.

Table 1: Secondary energy use in Canada in 2007 (13)

Source	**Percentage**
Space Heating	62.7
Water Heating	17.8
Appliance	13.3
Lighting	4.2
Space cooling	2
Total	**100**

Table 2: Space heating secondary energy use in Canada by energy source (13)

Source	**Percentage**
Natural Gas	53.9
Electricity	25.2
Wood	11
Heating Oil	8.3
Others	1.6

Although wind is problematic when it comes to offering a continuous supply of electricity, it can be used for heating if storage is available. Hughes (14; 15), describes how wind-generated electricity can be used for space heating when combined with electric-thermal storage (ETS) systems. This work shows that despite the availability of thermal storage, intermittency means that there is still a need for backup electricity and there is still excess electricity.

Due to volatile fuel prices and CO_2 emissions, the transportation sector is looking at alternative means such as hybrids vehicles and plug-in electric vehicles (PEVs). The main difference between hybrids and PEVs is that hybrids use more than one source of energy to move the vehicle whereas PEVs use only electricity (16).

Since space heating is not required throughout the year and there is excess wind-generated electricity when using thermal storage, the excess can be used as a source of electricity for electric vehicles if they can be charged intermittently. By using the electricity for transportation, some or all of the energy needs of another important service can be met, potentially reducing greenhouse gas emissions and improving energy security.

1.1 OBJECTIVE

This thesis examines the potential of employing wind-generated electricity for both space heating (using ETS systems) and transportation (using PEVs). Two charging algorithms are considered, ETS-first, in which the wind-electricity is made available to ETS units first and any surplus to PEVs, and PEV-first, in which the wind-electricity is made available to the PEVs first and any surplus to the ETS units. The overall objective is to find ways of maximizing the use of wind-electricity for space heating and transportation, so that the amount excess wind is as little as possible.

1.2 ORGANIZATION

The remainder of the thesis is organized as follows.

Chapter 2 discusses intermittent sources of energy, loads that follow services (space heating, electric vehicles), and storage.

Chapter 3 introduces the readers to two loads that follow supply and describes the designing of the charging algorithms which will be used to charge these loads with intermittent supply.

Chapter 4 introduces the readers to space heating and vehicular battery demand for the city of Halifax, wind integration with the two services using the proposed charging algorithms and the results are discussed in detail.

The thesis concludes with Chapter 5, which discusses the advantages and disadvantages of both algorithms. Potential future work is also discussed.

Chapter 2 BACKGROUND

Renewable energy sources currently meet approximately 14 percent of energy demand world-wide and are expected to play a greater role in the future of energy (17). Countries are increasingly recognizing the potential role for renewable energy within a portfolio of low-carbon and cost-competitive energy technologies capable of responding to the emerging major challenges of climate change, energy security, and access to energy (18). In Canada almost 16 percent of the Canada’s primary energy is met by renewables (19). Among renewables, hydro-electricity supplies about 69 percent of Canada’s total electricity (19); for example, as of 2010, provinces like Manitoba (20) and Quebec (21) generated more than 90 percent electricity from hydroelectricity.

Among other renewables, wind has experienced a rapid growth in Canada. Canada had a total installed capacity of 1,846 MW from 1,400 wind turbines (19) by the end of 2007. The increase in installed wind power capacity in Canada over the past ten years is shown in Figure 1.

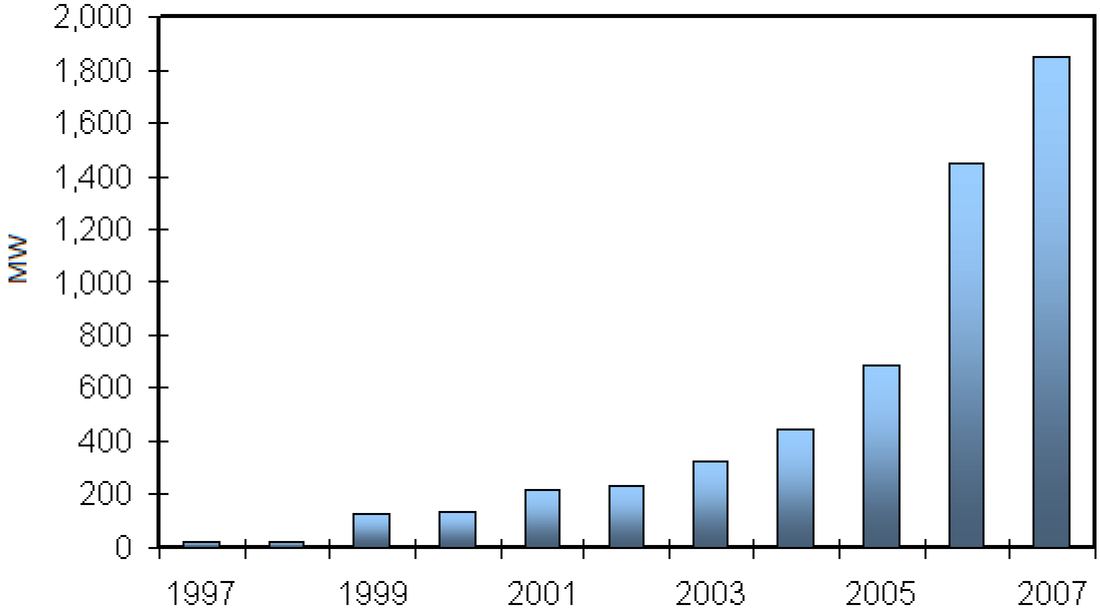

Figure 1: Installed wind power capacity in Canada (19)

In Nova Scotia, where 75 percent of its electricity is generated mainly by burning coal (22) and only 12 percent from renewables (23), plans to increase its share of renewable electricity by increasing its use of wind. Presently, wind farms across Nova Scotia generate over 100 MWh with 89 wind turbines (24). Over the next few years, Nova Scotia Power and independent producers plan to develop several additional wind farms, and hope to meet 18.5% of its demand from renewables sources like wind (25). With plans to develop wind in the province it is important that wind-generated electricity be utilized to its maximum potential.

The rest of this chapter discusses the interests and problems with wind power, loads not requiring on-demand supply of electricity, space heating and its importance and the role and importance of electric vehicles (EVs).

2.1 WIND POWER

Wind is the fastest growing energy source in the world (26) this increase is due to the growth of wind from a small base when expressed in terms of percentage appears to be a large value. Other reasons being (27):

1. Growing public awareness
2. Concern about climate change
3. Environmental issues related to other competing sources of energy
4. Awareness about oil and gas reserves depletion
5. Predicted peaking of global oil production
6. Improvements in wind turbine technologies

However, wind-generated electricity is not without its problems; for example (28):

1. Wind variability can be addressed by connecting many sites, but is an expensive solution.
2. Large power plants cannot respond quickly to sudden drop in wind power and must be already running if gas turbines or hydroelectricity are unavailable.
3. The wind turbines themselves use electricity and some even need input from the grid in order to function.
4. Onshore wind turbines destroy land due to erosion, disrupt water flow, trees need to be cleared. The spinning blades kill and maim birds and bats and the noise caused by the rotating turbine blades affect the lives of people in the neighbourhood. The low frequency caused by the offshore wind turbines is harmful to sea mammals.
5. Subsidies and regulatory favours are required to make investment.

A paper by Piwko, Osborn, Gramlich, Jordan, Hawkins and Porter (29) says that due to Renewable Standards that set a minimum requirement for renewables, wind generation projects are numerous and on the rise, but the intermittent nature of wind introduces new challenges. Although wind energy can be forecasted, forecast errors of 20-30% are not uncommon and add to the challenges of variability and uncertainty in power grids. The paper addresses these challenges and makes the following conclusions:

1. Due to the intermittent nature of wind some utilities limit the amount of wind into the power system.

2. Wind energy could result in increasing the amount of reserve and level of reliability, but adds that studies have shown that wind penetration of modest levels on the grid will not have a significant impact and hence should be encouraged.
3. Improvements in wind forecasting will play a key role in the success of wind energy.

A paper by Negrete-Pincetic, Wang, Kowli, Pulgar-Painemal (30) also focuses on intermittency and variability issues when wind energy is added to the power system. The paper states that wind intermittency and forecasting uncertainties constitute to two key barriers with integration of wind into the electricity grid and hence to incorporate wind would require a redefinition of the electricity commodity with emphasis on variability and uncertainty of wind energy. The paper concludes by stating that current ways to operate power systems and electricity markets needs to be upgraded to accommodate and fully exploit the wind resource.

Another conference paper by Etezadi-Amoli, Choma, Ahmad (31) supports the paper by Negrete-Pincetic, Wang, Kowli, Pulgar-Painemal and states that from a system point of view, wind generation does make a calculable contribution to system reliability.

A paper by Kiviluoma and Meibom (32) states that wind is becoming a new source of energy but wind is a variable and unpredictable power source. The authors claim that more flexible power systems would enable wind to be integrated at lower costs. This paper uses two new forms of flexibility, Plug-in electric vehicles and heat storage. The Balmorel model, a linear optimization model of a power system including district heating was used to carry out the analysis and the findings are:

1. If fossil fuel prices are high and the CO_2 emissions also have a cost associated with them, then according to the model wind and nuclear would dominate new power capacities.
2. With the introduction of flexibility, the share of wind power increased considerably as compared to all other power sources and also adds that if the cost of wind is low then the share of wind would be even higher.

The paper concludes by stating that the introduction of flexibility to the power system with the integration of heating and transport can actually induce cost-effective emission reductions in power production while simultaneously producing electricity for transport and heating with near-zero CO_2 emission sources. The flexibility benefits from plug-in electric vehicles could be larger than the costs of producing the electricity consumed by the vehicles, when power production investments are optimized to take full advantage of the flexibility.

A paper by Nguyen (33) describes a study for Vietnam for a 20 year period from 2005 to 2025 which examines the impact of wind energy on generation expansion and CO_2 mitigation and addresses issues such as energy security. The findings of the study were:

1. Due to its low environment impacts compared to coal, the development of wind has been strongly pushed in many countries.
2. Among alternative renewables wind is technically feasible due to its competitive production costs.
3. Wind energy presently cannot compete with fossils fuels and to make wind competitive carbon taxes or emission reduction targets need to be imposed.
4. The introduction of wind with emission constraints will change the generation mix and move towards technologies that emit less CO_2 (like gas turbines) and away from coal based power plants.
5. Addition of wind would help address energy security by reducing energy imports as well as contribute in CO_2 reduction.

The impact additional wind would have on the electricity grid is also of concern, a report published by IEA (34) addresses these impacts and the findings of the report are:

1. Wind power needs to be regulated and the importance of online information of both the production and demand levels as well as respective forecasts in their control rooms. This report takes countries such as Denmark, Spain, Portugal and Ireland as

example as these countries have integrated about 9-20 percent of wind into the electricity mix.

2. The benefit when adding wind power to power systems is reducing the total operating costs and emissions as wind replaces fossil fuels.
3. Wind generation may require system operators to carry additional operating reserves, due to the variability of wind power.
4. There is no need of new investments to increase the reserve capacity.
5. If interconnection capacity to neighbouring systems is allowed to be used for load balancing purposes, then the balancing costs are lower compared to the case where they are not allowed to be used.
6. The cost effectiveness of building new electricity storage is low for wind penetration levels of 10-20 percent. It is not cost effective to provide dedicated backup for wind in large power systems.

From the above papers and reports it was shown that even with intermittency and variability issues there is still an increase in wind energy. However, instead of using wind to satisfy base load or act as a replacement to continuous source of electricity, it could be used to service loads that have the ability to store energy as well as work without requiring a continuous supply of electricity. Hence, intermittent renewable energy sources such as wind can be used to target specific loads or services such as storage heaters and batteries.

2.2 SERVICES NOT REQUIRING AN ON-DEMAND SUPPLY OF ELECTRICITY

This section introduces two services that have the ability to store electricity and work for long periods of time without access to on-demand supply of electricity.

2.2.1 ELECTRICAL THERMAL STORAGE (ETS)

Electric Thermal Storage (ETS) heating was developed in Europe in the 1940s and introduced to the United States market in the 1980s (35). The ETS is an alternative to resistance or baseboard heating and is gaining popularity in North America; one manufacturer, Steffes, has sold over 100,000 units over the past 20 years (36). ETS units charge from the electricity grid during off peak hours which are periods when the electricity provider sells electricity at cheaper rates. The time of day (TOD) rates for the province of Nova Scotia are shown in Table 3 for the months of December, January, and February while the rest of the year rates are shown in Table 4.

Table 3: TOD rates in Nova Scotia (December to February) (37)

Time	Rate (cents/kWh)
07 am to 12 pm	15.320
12 pm to 04 pm	11.796
04 pm to 11 pm	15.320
11 pm to 07 am	06.028

Table 4: TOD rates in Nova Scotia (March to November) (37)

Time	Rate (cents/kWh)
07 am to 11 pm	11.796
11 pm to 07 am	06.028

Although they are charged between 11pm to 7am in Nova Scotia, in other jurisdictions a load control switch is installed at the site and is connected to one or more heaters. If the load control switch is addressable (wireless or power line communication), the ETS units can be controlled by the central utility (Dan Gaffney, personal communication, February 19, 2010). This feature can be used to turn on the ETS units whenever wind-generated electricity is available and turn them off during periods of limited or no wind as they can withstand continuous discharge cycles (38).

ETS unit consists of iron oxide ceramic bricks which are heated using an electric heating element and enclosed in a two layered insulation to retain heat. Fan assembly is used that directs the heat from the bricks to the surroundings. Figure 2 shows a cross-sectional view of an ETS unit.

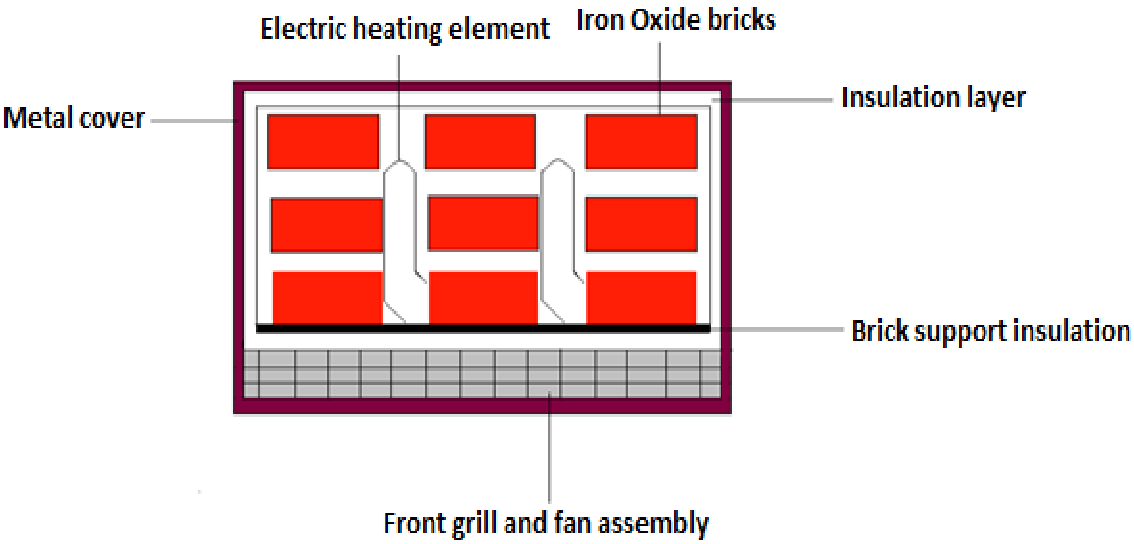

Figure 2: Cross sectional view of ETS

The ETS unit operates in one of four states (15):

1. **Charging:** when electricity is available to heat the ceramic bricks, the ETS will supply heat to them. If the environment is at the required temperature, the ETS diverts all the electricity to heating the bricks.
2. **Discharging:** when there is no electricity available to heat the environment, the ETS releases some of its stored thermal energy. The discharging is done in a controlled manner to ensure that the environment does not exceed the maximum specified temperature; when the maximum is reached, the ETS system enters the "off" state.
3. **Charging and discharging:** when electricity is available to heat the ceramic bricks and the environment is in need of heat, the ETS system will both charge and discharge.
4. **Off:** when the ETS system has heated the environment to the required temperature, it shuts off, thereby saving its thermal energy until more heat is required. A fully charged ETS system can retain its heat for up to a week (Dan Gaffney, personal communication, February 19, 2009).

2.2.2 PLUG-IN ELECTRIC VEHICLES (PEVs)

Electric cars were more popular and outsold the gasoline powered vehicles in the 1890s (39). By 1910, due to the easy availability of gasoline, the lack of power and limited distance that an electric car could travel and lack of infrastructure for electricity (39), gasoline powered vehicles replaced electric cars.

Presently, due to the advancement in battery technology, concerns over the environment, and volatile fuel prices, there is renewed interest in electric vehicles (EV), JP Morgan estimated that by 2020 11 million electric vehicles could be sold worldwide, including 6 million in North America alone (40). With the number of electric vehicles increasing the electricity used to run these vehicles can come from a variety of sources, from fossil fuels to renewables energy sources.

There are different variations of electric vehicles; for example, the Plug-in Electric Vehicle or PEV is designed to be charged from a wall socket. Some PEVs available now are:

- Tesla roadster
- Chevy volt
- Nissan leaf

For example, the Tesla roadster is a zero tailpipe emission vehicle which is built and designed by Tesla Motors. Its battery pack contains 6,831 lithium ion cells and is the most energy-dense pack in the industry, storing 56 kWh of energy (41). The Lithium-ion battery pack can be recharged before being completely drained out and hence this feature can be used to charge the Tesla Roadster as and when wind-electricity is available.

This section has shown that the ETS and the Tesla Roadster battery pack can be charged intermittently and, as a result, should be investigated as potential services that can be integrated with wind-electricity.

2.3 SPACE HEATING

In the Canadian residential sector, energy is used for a variety of activities such as space heating, water heating, appliances, lighting, and space cooling. Space heating is essential in Canada due to a long heating season and account for 63% of the residential end energy use as shown in Figure 3.

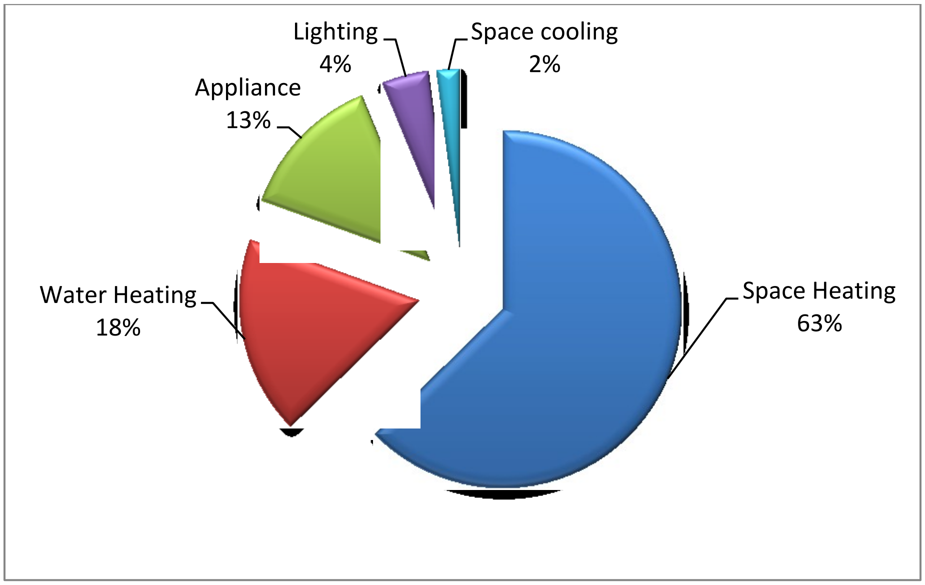

Figure 3: Space Heating Secondary Energy Use (42)

25% of space heating is supplied by electricity as shown is Figure 4 and the percentage of space heating met from electricity has been increasing (43).

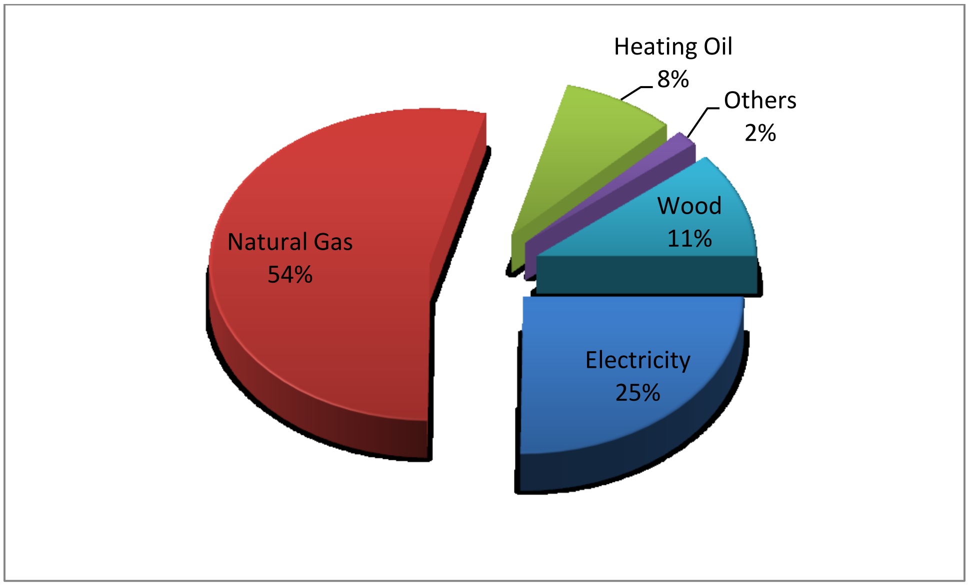

Figure 4: Space Heating Secondary Energy Use by Energy Source (43)

Since space heating is an important service that has to be met in northern countries coupled with interest in wind, research has been done in these two topics and a few are discussed below.

A report by Steffes (38) in which the author refers to the synergy of the wind energy and the ETS as "Wind assisted heating". The reports claims that utilities can meet there renewables energy standards with the help of this synergy as well as utilize the wind resource better in the future. The author suggests that, as the wind blows more during the heating season, and on an average, more during the off-peak hours, it can be used to charge the ETS units, which the author also refers as thermal battery. The ETS units have proven that they can be used with the wind as they can withstand continuous daily deep discharge cycles.

An article in the Globe and Mail (44) reports that the city of Summerside which is the second largest city in the province of PEI is using wind generated electricity to supply roughly 48% of the load over the year from wind and at certain time periods can meet even 100% of the load. The report also suggests that at times more wind electricity is generated than the load requires especially during the off-peak periods (11am to 7am) and hence are providing incentive to residents of the city to install storage heaters (ETS units) and use this excess wind to meet their space heating needs. They are currently working on setting up 100 test homes by the end of the year 2010 and run fiber optic cables to these 100 homes to monitor their energy demands.

By doing so they are trying to shift the on-peak load to off-peak which would help flatten the load curve and allow a more efficient purchase of electricity at all times. In addition, Summerside is also planning to use the city as a test site for using the electric vehicles as a source of storage for wind-generated electricity.

The paper by Hughes (4) was the main source of inspiration for my thesis. The author explained the present problem such as depleting fossil fuels, energy security, and climate change and suggested that even though wind generated electricity may be an intermittent source of energy it can be integrated with loads that do not require a continuous supply of electricity if they have the ability to store energy. The author integrated wind generated electricity with space heating using baseboard heaters as well as the ETS units. As the ETS units did not require a continuous supply of electricity compared to the baseboard heaters, they were a viable option and the results showed that up to 500 households 95% of the annual space heating could be met with the wind alone.

Hence it is clear that space heating using the ETS units can be a viable option to be integrated with wind generated electricity and by doing so would address issues such as energy security and reduction in GHG emissions.

2.4 ELECTRIC VEHICLES AND STORAGE

Electric vehicles are going to play an important role in the future as they can decrease the dependence on gasoline (45) as well as act as storage using the Vehicle-to-Grid (V2G) technology (46). This section discusses the impacts that the electric vehicles would make in the future to the electricity system and the environment impacts.

A paper by Brown, Pyke and Steenhof (40) discusses the future role and importance of electric vehicles (EVs) and states that "by 2020 11 million EVs could be sold worldwide, including 6 million in North America" and in order to make this transition to the future which consist of EVs as viable model of transportation, it is important to establish standards for EVs and related technologies along with areas where new standards may be necessary.

In this paper, authors first discuss the major impacts that EVs will have; such as the electricity system impacts, which would lead to an increase in electricity generation. This increase in generation will not be a large spike and will be influenced by the car owners charge their vehicles. The majority of the car owners will be charging EVs during the off-peak hours this would result in smoothened demand over the 24 hour period. In Canada, it has been estimated that half a million EVs by 2018 would increase night time electricity demand by upwards of 40%, while only having minor impacts on demand levels in the daytime. The next issue the authors discuss is the reduction in greenhouse gas (GHG) emissions which would greatly depend in which jurisdiction (source of energy used) the EVs are charged in. The third major impact is the use of EV batteries as a storage device that could be charged at night. The authors state that in order for all this to work smoothly standards are required in electrical systems and vehicle-to-grid technology, batteries and EV recharge infrastructure, consumer and vocational environments.

A paper by Perujo and Ciuffo (47), to estimate the possible impact of electric vehicles on the electricity grid in terms of energy, power requirements and CO_2 abatement was carried out for the Province of Milan till 2030 and had the following findings:

1. The penetration of EVs (20-25%) would have negligible impacts on the annual energy consumption.
2. Without a proper regulation the EVs could have a great impact on the daily electric power request

3. The results showed that with the increased penetration of EVs into the market would reduce CO_2 emissions.

A paper by Aksoy (48) was a study conducted for Turkey which was intended to forecast the electricity demand and consumption by battery electric vehicles (BEV). The main conclusion was that the demand for electricity to recharge the BEV cannot be generated by existing power plants and at best a mid-size power plant is required every year for the next 10 to 15 years.

Another paper by Hadley and Tsvetkova (49) also supports the conclusion made by Aksoy by stating that PHEV penetration of the vehicle market is likely to create substantial changes for the electrical grid. The demand, generation, electricity prices, and emissions from the utilities created by the introduction of PHEVs are expected to go up and in some regions lead to negative consequences if nothing is changed.

A paper by Lindly and Haskew (45) discusses the impacts EVs would have on the GHG emissions. The authors state that as vehicles which use gasoline are the major contributors towards transportation industries CO_2 and other emissions that affect global warming and climate change, there is an interest in EVs as they can reduce emissions. While EVs can reduce emissions, but when charged would increase emissions at the power generation sites therefore this paper develops a methodology that predicts the net emission impacts. This methodology can be applied to any geographical area, but this paper uses the state of Alabama as a case study and the results of the paper shows that for a 10% EV penetration there was a reduction of about 1.8% of CO_2 for the year considered.

Peterson, Whitacre, and Apt (46) examine the economic benefits that a PHEV owner would make if they made use of the V2G energy sales. This analysis was carried out for three cities namely, Boston (BOS), Rochester NY (ROC) and Philadelphia (PHL), and was simulated using the battery capacity of the Chevy Volt (16 kWh). The results of this analysis showed that the maximum annual profit with perfect electricity market information and no battery degradation cost is $142 to $249. With degradation included; the maximum annual profit is $12 to $118.

A final paper that addresses the need for an infrastructure for daytime charging system to charge the PHEVs (50); give the example that most PHEVs are designed for a 40 mile driving range based on the average driving distance. There are still commuters that will need to travel more than 40 miles and will need to recharge their PHEVs to avoid using gasoline. The authors created a mathematical model to solve the PHEV Charging Infrastructure Planning (PCIP) Problem and performed a case study for Oak Ridge National Laboratory (ORNL) campus by reviewing the driving profiles of the ORNL employees and this model confirmed the need for daytime charging systems.

Hence it is clear that the EVs can contribute significantly towards addressing environmental impacts if they are charged using a carbon-free source, but would require new energy source to meet its demand. Wind-electricity would appear to be one possible candidate as a potential source of electricity for PEVs.

2.5 SUMMARY

This chapter discussed the interests and problems associated with wind energy and the need to target loads/services not requiring continuous supply of electricity. Loads such as ETS for space heating and PEVs for transportation were introduced and discussed in detail. The importance of space heating in Canada as well as the growth of EVs was also discussed in this chapter.

Chapter 3 METHODS AND IMPLEMENTATIONS

In 0, it was shown that wind generated electricity is not suitable for base load supply, but can be used with loads that do not require a continuous supply of electricity. This chapter introduces two charging algorithms designed for residential space heating (ETS units) and transportation (PEVs), which can be charged with an intermittent supply, such as wind. The decisions regarding the implementation of the algorithms are also discussed.

3.1 THE CHARGING ALGORITHMS

The charging algorithms are to share the available wind-generated electricity between the ETS and PEV units. Two algorithm choices were considered:

1. Charge the ETS first and then, if wind is available, apply it to the PEV units (ETS-first).
2. Charge the PEVs first and then, if wind is available, apply it to the ETS units (PEV-first).

ETS-first gives priority to the ETS units to charge first from the wind generated electricity and if surplus wind is available it is then supplied to the PEVs, while in PEVs-first, the PEV units are charged first and then if wind is available, it is given to the ETS.

3.2 DESIGN

This section describes the timeframe, flowchart, charging times, and the charging algorithms used to service space heating and PEV's battery charging.

3.2.1 TIME FRAME FOR ANALYSIS

It is important to choose a timeframe for the data analysis as it would help understand the data and perform the analysis in a timely manner. Smaller the time frame more detailed analysis of the data set can be carried out. Depending upon the availability of the data, analyses can be carried out monthly, weekly, daily, hourly, or by the minute. Ideally minute-to-minute analysis would be the best choice for the algorithms, as it would be real time; however, hourly analysis was performed and the design is based upon an assumed availability of hourly data.

3.2.1.1 *Flowchart*

As the wind will be used to charge both ETS and PEV units, the idea is to design an algorithm in such a way that the wind is used to satisfy either ETS or PEV demand first and, if wind is still available, it will be used to charge the PEV or ETS units. The charging of PEVs and ETS units should be based on their respective hourly charging rates and maximum allowable capacity and the PEVs are discharged according to the daily driving requirements and the ETS according to the hourly space heating demand. Any remaining wind after servicing the ETS or PEV will be considered excess and will be available for other uses.

For example, the flowchart in Figure 5 is for hourly data and with this data, a detailed algorithm is designed to charge the ETS and PEV units. The terms used in the flowchart are defined as:

Wind available: is the wind input data available for that hour.

First service: according to the algorithm can be either ETS or PEV units.

Surplus wind: is the wind available after satisfying the first service demand.

Second service: according to the algorithm can be either PEV or ETS units.

Excess wind: is the surplus wind available after satisfying the second service demand.

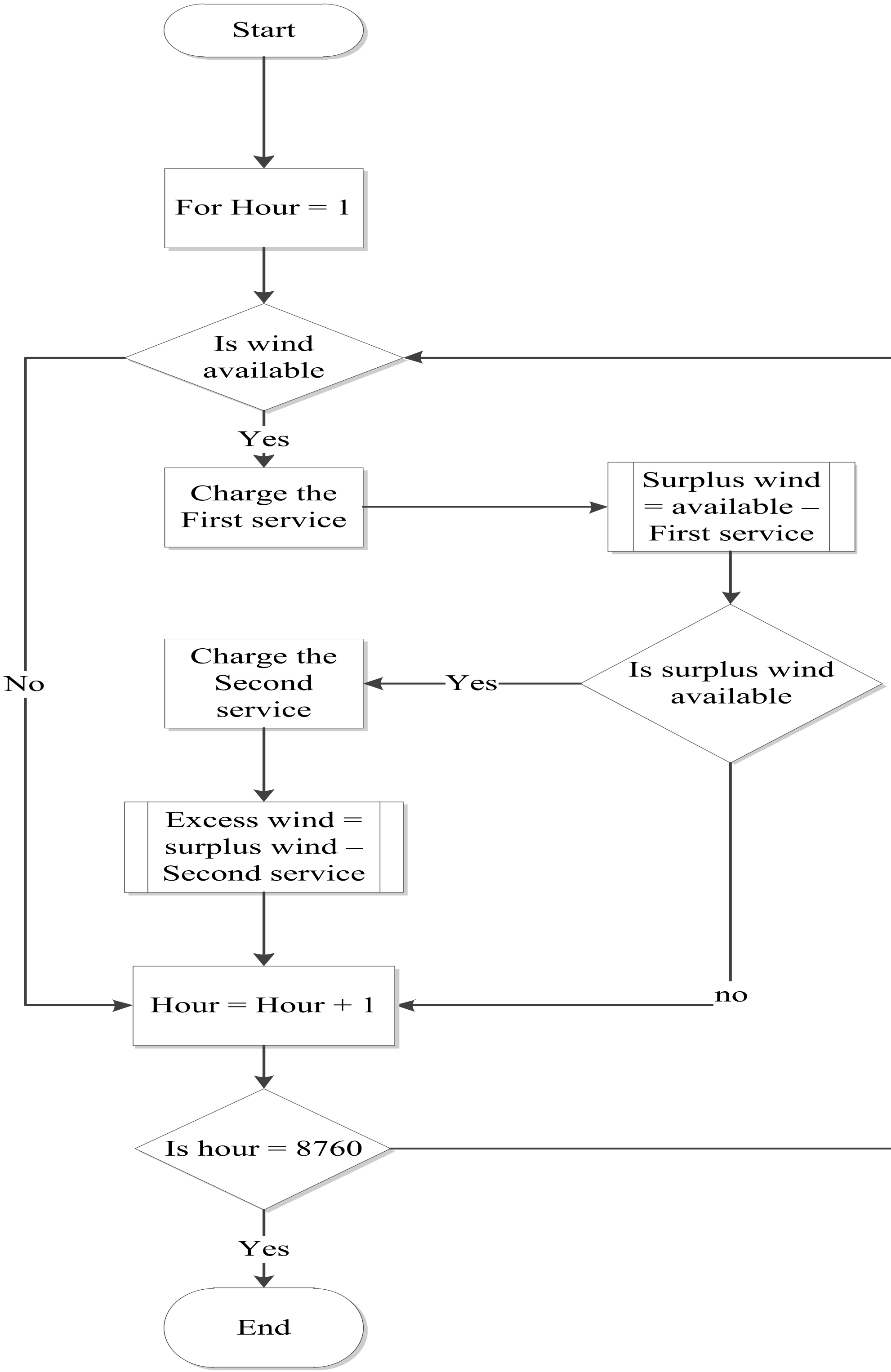

Figure 5: Charging algorithm design flowchart.

The flowchart shows how the charging algorithms are to be designed. If the analysis is done hourly, the design checks for the first hour and the amount of wind available. If wind is not available it skips to the next hour, but if wind is available then it is first used to charge the first service (i.e., ETS or PEV units). If the service is space heating using the ETS units, the wind is used to first satisfy the space heating demand for that hour and if wind is l remaining to top up the ETS units whereas for the PEVs the wind is used to top up the battery.

Once the First service is attended the design checks if any wind is still remaining, this remaining wind is termed as surplus wind which will be used to charge the Second service (i.e., PEV or ETS). If surplus wind is not available, the control skips to the next hour. The excess wind is calculated and continues to the next hour. This cycle repeats for a year or 8760 hours, after which the process comes to an end.

3.2.2 CHARGING TIMES

The ETS units are always connected to the grid and hence can be charged at any time throughout the day, whereas the PEVs can only be connected to the grid when not being driven. Therefore, PEV charging is done by either:

Overnight charging – since the majority of the electric vehicle manufacturers claim that most of these cars are idle for overnight charging (51), the charging period is during the off-peak hours between 23h and 7h.

Anytime charging – charge the PEVs throughout the day except at times when they are in motion; for the purposes of this thesis, it is assumed that the PEVs will be in use at the following times: morning commute (8h to 9h), lunch commute (13h to 14h) and evening commute (17h to 18h). The following commuting times were chosen as it was assumed that the work timings are from 9h to 17h every day. During the weekends it is assumed that the car owners drive longer distances and the PEVs are charged only during off-peak hours.

3.2.3 OVERNIGHT CHARGING

The algorithms for overnight charging with the ETS-first and PEV-first algorithms are discussed separately below.

3.2.3.1 *ETS-first algorithm*

In this charging algorithm the objective is to use the available wind to charge the ETS units and if any surplus wind is available between 23h and 7h, the PEVs are charged. The excess wind remaining after charging both the services is available for export or other uses. The ETS-first algorithm is as follows (note that for simulation purposes, the PEV is discharged at 23h):

```
1. For each Day of the year
2. For each Hour in the day
3. Calculate the available wind for the hour (Available); if Available is equal to zero,
   skip to step 7.
4. Calculate the required energy for ETS units for the hour (ETS energy), up to the
   maximum rate of hourly recharge.
5. If Available < ETS
       a. Distribute Available equally amongst the ETS units (limited to full capacity)
       b. Skip to step 7
   Else
       a. Distribute ETS energy amongst the ETS units (limited to full capacity)
       b. Surplus = Available – ETS energy
6. If Hour between 23h and 7h
       a. If Hour is 23h
              i. Decrease PEV energy by the daily driving requirements of each PEV
       b. Calculate the required energy for all PEVs for the hour
       c. If Surplus < PEV
              i. Distribute Surplus equally amongst the PEV units (limited to full
                 capacity)
             ii. Skip to step 7
          Else
              i. Distribute required PEV energy amongst the PEV units (limited to full
                 capacity)
             ii. Excess = Surplus – PEV energy
    Else
       a. Excess = Surplus
7. Each hour, decrease ETS by the required energy to meet Hour's heating demand
```

```
8. Next Hour
9. Next Day
```

3.2.3.2 *PEVs-first algorithm*

In this charging algorithm, PEVs are charged first. The objective of this algorithm is to use the available wind to charge the PEVs between 23h and 7h and, if any surplus wind is available during these hours, it is used to charge the ETS units along with the wind between 7h and 23h. The excess wind remaining after charging both the services is available for other uses or export. The PEVs-first algorithm is as follows:

```
1. For each Day of the Year
2. For each Hour in the Day
3. Calculate the available wind for the hour (Available); if Available is equal to zero,
   skip to step 7.
4. If Hour between 23h and 7h
       a. If Hour is 23h
              i. Decrease PEV by the daily driving requirements of the PEVs.
       b. Calculate the required energy for PEVs for the hour (PEV energy)
       c. If Available < PEV energy
              i. Distribute Available equally amongst the PEV units (limited to full
                 capacity)
             ii. Skip to step 7
       Else
              i.  Distribute Available amongst the PEV units (limited to full capacity)
             ii.  Surplus = Available – PEV energy
   Else
       a. Surplus = Available
5. Calculate the required energy for all ETS for the hour (ETS energy).
6. If Surplus < ETS energy
       a. Distribute Surplus equally amongst the ETS units
       b. Skip to step 7
   Else
       a. Distribute required ETS energy amongst the ETS units
       b. Excess = Surplus – ETS energy
7. Each hour, decrease ETS by the required energy to meet hour's heating demand
8. Next Hour
9. Next Day
```

3.2.4 ANYTIME CHARGING

The ETS-first and PEV-first algorithms for anytime charging are discussed below.

3.2.4.1 *ETS-first algorithm*

In this charging algorithm the objective is to use the available wind to charge the ETS and, if any surplus wind is available, charge the PEVs for 21 hours on weekdays and 8 hours on the weekends. The excess wind remaining after charging both the services is available for export or other uses. The ETS-first algorithm is as follows (note that for simulation purposes, the PEV is discharged at 8h, 13h, and 17h; on the weekends at 23h):

```
1. For each Day of the year
2. For each Hour in the day
3. Calculate the available wind for the hour (Available); if Available is equal to zero,
   skip to step 7.
4. Calculate the required energy for ETS units for the hour (ETS energy), up to the
   maximum rate of hourly recharge.
5. If Available < ETS
       a. Distribute Available equally amongst the ETS units (limited to full capacity)
       b. Skip to step 7
   Else
       c. Distribute ETS energy amongst the ETS units (limited to full capacity)
       d. Surplus = Available – ETS energy
6. If Hour is 8h and 13h and 17h and 23h(weekends)
       a. Decrease PEV energy by the commuting requirements of each PEV
    Else
       b. Go to next step
7. If hour is between 23h and 7h on weekends and other than 8h, 13h and 17h on
   weekdays
       a. Calculate the required energy for all PEVs for the hour
       b. If Surplus < PEV
              i. Distribute Surplus equally amongst the PEV units (limited to full
                 capacity)
             ii. Skip to step 7
          Else
            iii. Distribute required PEV energy amongst the PEV units (limited to full
                 capacity)
             iv. Excess = Surplus – PEV energy
   Else
       a. Excess = Surplus
8. Each hour, decrease ETS by the required energy to meet Hour's heating demand
9. Next Hour
10. Next Day
```

3.2.4.2 *PEVs-first algorithm*

In this charging algorithm, PEVs are charged first. The objective of this algorithm is to use the available wind to charge the PEVs for 21 hours on weekdays and 8 hours on weekends and, if any surplus wind is available, ETS units are charged. The excess wind remaining after charging both the services is available for other uses or export. The PEVs-first algorithm is as follows:

```
1. For each Day of the Year
2. For each Hour in the Day
3. Calculate the available wind for the hour (Available); if Available is equal to zero,
   skip to step 7.
4. If Hour is 8h and 13h and 17h and 23h (weekends)
          a. Decrease PEV energy by the commuting requirements of each PEV
   Else
          b. Go to next step
5. If hour is between 23h and 7h on weekends and other than 8h, 13h and 17h on
   weekdays
          a. Calculate the required energy for all PEVs for the hour
          b. If available < PEV
                  i. Distribute Surplus equally amongst the PEV units (limited to full
                     capacity)
                 ii. Skip to step 7
        Else
                iii. Distribute required PEV energy amongst the PEV units (limited to full
                     capacity)
                 iv. Surplus = Available – PEV energy
   Else
       b. Surplus = Available
5. Calculate the required energy for all ETS for the hour (ETS energy).
6. If Surplus < ETS energy
          a. Distribute Surplus equally amongst the ETS units
          b. Skip to step 7
   Else
       c. Distribute required ETS energy amongst the ETS units
       d. Excess = Surplus – ETS energy
7. Each hour, decrease ETS by the required energy to meet hour's heating demand
8. Next Hour
9. Next Day
```

3.3 IMPLEMENTATION

This section describes the theoretical limit to the number of households and PEV batteries that can be serviced with the available wind supply data, the platform chosen to carry out the analysis and examples of the application of the algorithms..

3.3.1 WIND-ELECTRICITY: THEORETICAL POTENTIALS

The following considers how the PEVs and ETS units could be serviced with wind-generated electricity. It presents a theoretical estimate as to the number of ETS and PEVs that could be charged with the available wind.

3.3.1.1 *TOTAL NUMBER OF HOUSEHOLDS HEATED WITH THE WIND*

The theoretical number of single-detached households that can be heated with the wind is shown in Eq (1). The analysis is from hour 1 to hour 8760 (8760 hours equals one year) for the hourly wind supply by the hourly space heating demand for the whole year.

$$\sum_{h=1}^{h=8760} \frac{hourly\ wind\ supply}{hourly\ space\ heating\ demand} \tag{1}$$

3.3.1.2 *NUMBER OF PEVs CHARGED WITH WIND*

As there are two different approaches to battery-charging: Overnight and Anytime; they are discussed separately.

3.3.1.2.1 Overnight charging (23h - 7h charging)

The theoretical maximum number of PEVs that can be charged with the wind between 23h and 7h is shown is Eq (2).

$$\sum_{Day=1}^{Day=365} \frac{\sum_{h=23}^{h=7} Wind\ supply_{Day,hour}}{Battery\ demand_{Day}} \tag{2}$$

3.3.1.2.2 Anytime charging (21 hours a day)

The theoretical number of PEVs that can be integrated with the available wind supply is given by Eq (3).

$$\sum_{Day=1}^{Day=365} \frac{Wind\ Supply_{Day}}{Battery\ demand_{Day}} \tag{3}$$

3.3.2 DATA REQUIRED

To implement the algorithms, the following data is required:

Hourly wind production data: this will be used to charge the PEVs and ETS units.

Hourly temperature data: will be used to calculate the hourly demand which is the demand for space heating that an average household needs for that hour.

Maximum hourly charging rate of the ETS unit: the maximum value that the ETS can be charged on an hourly basis with the available wind. This data was extracted from manufacturer's data sheet.

Maximum charging rate of the PEV battery: the maximum value that the PEVs can be charged on an hourly basis with the available wind. This data was extracted from manufacturer's data sheet.

Daily battery demand: is the demand for the PEV according to daily driving distance. Since this was not readily available, it was extracted from the daily commuting distance to work and the annual driving distance.

For the hourly analysis to be carried out, the hourly average household space heating demand was not readily available and had to be estimated using the following steps:

- Calculate the Heating Degree Hours (HDH) which is commonly used in the heating, ventilating, and air conditioning (HVAC) industries to estimate energy consumption by heating systems during the winter season (52). By using Eq (4) and the hourly temperature data, where BT_H is the base temperature (15°C) and OT_H is the outside temperature.

$$\mathrm{HDH} = \sum_{h=1}^{h=8760} BT_H - OT_H \tag{4}$$

- Calculate the percentage of each hour's HDH by dividing each hour's HDH by the sum of all HDH (Eq (4)) as shown in Eq (5). This gives a measure of the energy required for a given hour and is expressed in terms of percentage.

$$\text{Percentage HDH} = \frac{\text{HDH}}{\text{Sum of HDH}} \tag{5}$$

- By multiplying the annual space heating value by the percentage of HDH for each hour, the hourly demand can be obtained, as shown Eq (6).

$$\text{Hourly Demand} = \text{Percentage HDH} \times \text{Total annual space heating value} \tag{6}$$

3.3.3 SIMULATION SAMPLE

In this section the implementation of the algorithm is described along with the illustration of the results for both the algorithms for the city of Halifax. The implementation of the algorithm is done to show how the data analysis takes place and to better understand the working of the algorithm.

The example shown below is for the ETS state of a single ETS unit controlled by the ETS-first algorithm. Table 5 consists of two input columns, temperature (column C) and wind from which the hourly demand (column E), ETS state (column F) and excess wind (column G) were calculated. On December 25 at 16h the outside temperature was 1.2^0C, wind was unavailable, the hourly demand was 3.10, the ETS state was 143.93 kWh and since there was no wind the excess wind was also zero. At 17h the algorithm first checks the available wind (step 3 of the ETS-first algorithm) and since it's zero, reduces the ETS by the required energy to meet the hours heating demand (step 7) and reduces to 140.77 kWh and the algorithm jumps to the next hour (step 8). At 18h the algorithm again checks if the wind is available (step 3) since it is available calculates the required energy of the ETS (step 4). The algorithm checks if the available wind is less than the ETS energy required for that hour (step 5), and distributes it among the ETS and calculates the surplus wind which is 236.91 kWh, and the algorithm goes to the next hour. At 19h the algorithms works the same as the previous and tops up the ETS to full capacity of 180 kWh after meeting the hourly demand and has a surplus wind of about 785 kWh.

Table 5: ETS state

A	B	C	D	E	F	G
Day	Time	Temperature (°C)	Wind (kWh)	Hourly Demand (kWh)	ETS (kWh)	Surplus Wind (kWh)
25	16:00	1.2	0.00	3.10	143.93	0
25	17:00	0.9	0.00	3.16	140.77	0
25	18:00	0.7	262.50	3.21	166.36	236.91
25	19:00	0.9	798.00	3.16	180	784.36

The hourly demand is calculated using the formulae as described in section 3.3.2.

The ETS state is calculated using the Hourly demand and the wind columns data, the Eq (7) below is used to calculate the Hourly demand.

$$\text{ETS} = (\text{Previous hour's ETS value}) - (\text{Hourly demand}) + \text{Wind (limited to charging rate)} \tag{7}$$

The surplus wind is calculated using Eq (8).

$$\text{Surplus Wind} = (\text{Wind}) - (\text{ETS} - \text{Previous hour's ETS value}) \tag{8}$$

The example is for the PEVs state in the PEV-first algorithm with Overnight charging. According to this algorithm the PEVs are discharged at 23h and the charging occurs from 23h to 7h. Table 6 consists of 3 input columns, Wind (column B), Charging rate (column C) and Discharge (column D) from which the PEV state (column E) and Surplus Wind (column F) is calculated. On July 20 at 22h the wind input was 26.70 kWh and the PEV state was 56 kWh (fully charged) and the charging and discharging was zero since it was not the charging period (23h to 7h). At 23h the algorithm first checks if wind is available (step 3 of PEV-first algorithm), then if the hour is between 23h and 7h (step 4 of PEV-first algorithm), as the hour is 23h it decreases the PEV by the daily driving requirement (5.3 kWh) and then calculates the required energy for PEV (step 4b) and distributes the available to PEV (step 4c) which reaches 52.30 kWh and goes to the next hour (step 8). At 0h the algorithm checks for available wind (step 3) and if the hour is between 23h and 7h (step 4)to calculates the required energy for PEV (step 4b) and distributes the available to PEV (step 4c) which reaches 56 kWh and goes to the next hour (step 8). At 1h the algorithm works the same as the previous hour but tops up the PEV and calculates excess wind which was about 54 kWh.

Table 6: PEV state

A	B	C	D	E	F
Time	Wind (kWh)	Charging rate (kWh)	Discharge (kWh)	PEV (kWh)	Surplus Wind (kWh)
22:00	26.70	0.00	0.00	56.00	26.70
23:00	2.00	16.80	5.70	52.30	0.00
0:00	1.60	16.80	0.00	54.90	0.00
1:00	54.90	16.80	0.00	56.00	53.80

The PEV state is calculated using Eq (9).

$$\text{PEV} = (\text{Previous hour's PEV value}) - (\text{ Discharge}) + (\text{Wind}) \tag{9}$$

The Surplus wind is calculated using Eq (10).

$$\text{Surplus Wind} = (\text{Wind}) - (\text{ ETS} - \text{Previous hour's ETS value}) \tag{10}$$

From Table 5 and Table 6, it was shown how the charging of ETS and PEV units can be simulated using the algorithms which consisted of equations that needs to be compared and calculated. Hence it was decided to implement the algorithm as a spreadsheet model. It was important to choose a spreadsheet simulation platform which would help achieve what was shown in Table 5 and Table 6 and allow graphical representation of data if needed.

3.3.4 SIMULATION PLATFORM

A collection of data has to be used in order to carry out the two algorithms. This data had to be broken down into discrete time steps (hourly) that makes the use of arrays more appropriate. It is a simple step to go from an array of data to a spreadsheet hence Excel spreadsheet was chosen. A few other reasons for choosing Excel spreadsheets are:

1. Most popular spreadsheet software.

2. Allows graphical representation of the data.
3. Allows simple commands to be written into cells
4. Complex computations can be done with the help of statements or built-in functions.

3.4 SUMMARY

This chapter introduced two charging algorithms ETS-first and PEV-first, which were used for space heating and PEVs battery charging, along with different versions, namely Overnight and Anytime charging. The simulation platform used and sample results were discussed.

The application of the algorithm to heating and driving in Halifax and the results obtained are discussed in detail in Chapter 4.

Chapter 4 TESTING AND RESULTS

In this chapter, the charging algorithms developed in Chapter 3 are applied to the space heating and transportation demands of Halifax, the capital of Nova Scotia (NS) and the largest city in Atlantic Canada. Halifax was chosen over Charlottetown (PEI) for both residential heating and commuting since data was available at the time of this analysis for the city of Halifax. The available wind resource and the annual demands for space heating and battery charging are also discussed.

4.1 WIND RESOURCE

Due to its geographic location, parts of Atlantic Canada have excellent wind potential (53). The wind data for this research was obtained from the North Cape wind farm located near the town of Tignish, Prince Edward Island (PEI). The wind farm, developed by the Prince Edward Island Energy Corporation (PEIEC), consists of eight Vestas V47 turbines each rated at 660 kW giving a total installed capacity of 5.28 MW (54). The data covers the period from 1 July 2005 until 30 June 2006 and the total annual output for this period was 32.31 GWh. The monthly output of the wind farm is shown is Figure 6. The data is plotted from July to June as this distribution of data allows the heating season to be central to the graph.

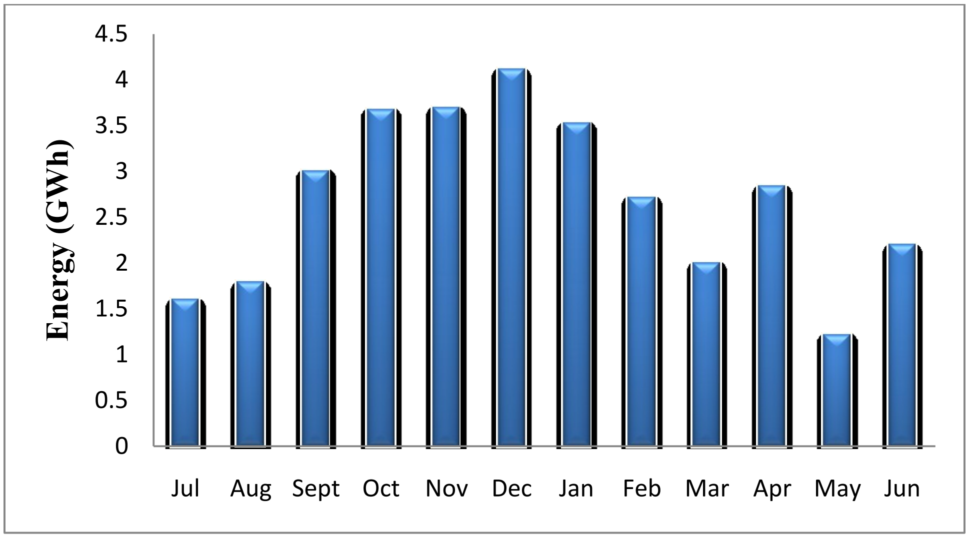

Figure 6: Monthly wind output for 2005-2006

4.2 RESIDENTIAL SPACE HEATING

Before discussing residential space heating, it is necessary to examine the residential sector to review and select the type of household structure for the analysis.

4.2.1 RESIDENTIAL SECTOR

A review of Nova Scotia's residential sector shows that almost 68 percent of the households are single-detached (see Figure 7); hence this work focuses on satisfying the space heating needs of single-detached households.

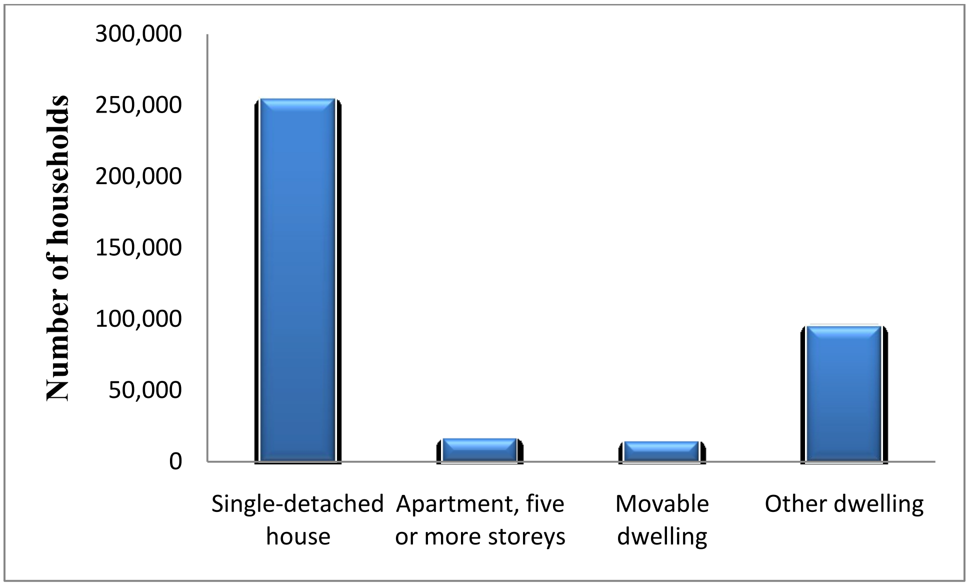

Figure 7: Private households by structure type in Nova Scotia (55)

4.2.2 SPACE HEATING

In Canada, energy is mainly used in the residential sector for space and water heating, appliances, lighting, and space cooling. Space heating is essential in Halifax due to its seven month heating season (October to April). Space heating combined with water heating accounts for most of the residential energy end-use, as shown in Table 7.

Table 7: Single Detached Secondary Energy Use by service for Halifax (43)

Service	kWh	Percentage
Space Heating	16,289	58.7%
Water Heating	4,371	15.7%
Appliances	5,106	18.4%
Lighting	1,915	6.9%
Space Cooling	56	0.2%
Total	27,736	100%

For the hourly analysis to be carried out, the hourly average household space heating demand was not readily available and had to be estimated using the equations from section 3.3.2 and 3.3.1.1 and the theoretical number of single-detached households that can be heated with the wind for 2005-2006 was 1984.

Error! Reference source not found. Figure 8 shows the monthly space heating demand for a single-detached household in Halifax in 2005-06, obtained by adding the hourly demands for the respective months.

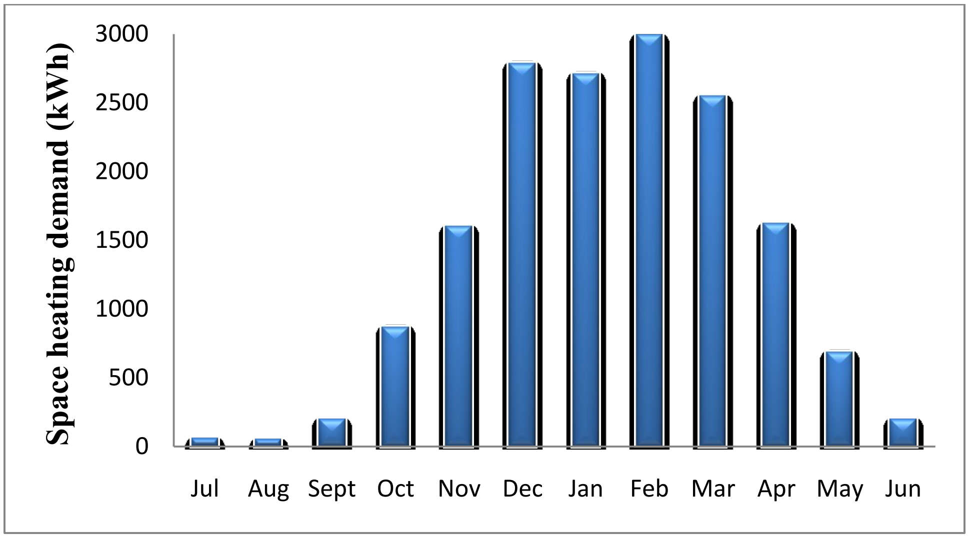

Figure 8: Monthly space heating demand for Halifax

4.2.3 SIZING THE ETS

Since the space heating needs of the household will be met by an ETS unit, it is important to size the ETS for the household's expected demand. From the hourly demand calculated for the city of Halifax using the hourly temperature data from Environment Canada (56) for 2005-2006 the maximum hourly demand was found to be 7.4 kW. Since the number of hours of charge the units receive is eight hours in the off-peak between 11:00 pm to 07:00, the ETS units must be charged to at least 118.4 kW to provide sufficient heat for the remaining 16 hours.

Table 8: Steffes Corporation Comfort Plus Hydronic 5100 ETS unit (57)

Specifics	**Model**		
	5120	**5130**	**5140**
Storage capacity (kWh)	120	180	240
Charging input (kW)	19.2	28.8	38.4
Maximum discharge for 8 hours consecutive charge (kW/hr)	8.21	12.3	16.4

It is assumed that the ETS units are in the charge-discharge cycle and the rate of discharge is 7.4 kW, with the respective charging rates.

Table 9: Capacity of ETS after 8 hours of charge-discharge

Model		
5120	**5130**	**5140**
94.4 kW	171.2 kW	248 kW

As the model 5130 and the model 5140 ETS units have a greater capacity than 118.4 kW (minimum required), the model 5130 was chosen as its value was closer to the minimum capacity required of 118 kW. These calculations refer to off-peak charging because in case of wind shortfalls, the best options for backup are the off-peak hours as they will not add to the peak and the costs associated with off-peak hours is less (58).

4.3 PLUG–IN ELECTRIC VEHICLES

The PEV chosen for this thesis is the Tesla Roadster, consisting of a 375 volt AC induction air-cooled electric motor with variable frequency drive with top speed of about 200 km/hr (125 miles/hr) and can travel about 394 km (245 miles) on a full recharge (59). The battery capacity is 56 kW (41). The Tesla Roadster is available in Canada and the United States. This PEV was chosen as at the time of this analysis because more detailed specifications were available compared to other brands

4.3.1 MODE OF TRANSPORTATION, DISTANCE TRAVELLED AND TIME TAKEN PER DAY TO WORK

Most Canadians drive or ride in cars, vans, buses or trucks for personal transportation (60). The average distance travelled in Nova Scotia is 5,011 km per quarter (61), or annual average driving distance of 20,044 kms. Table 10 shows the mode of transportation for the city of Halifax and about 76 percent of the people who commute to work either drive or travel as passengers in car, trucks, or vans.

Table 10: Mode of Transportation in Halifax (62)

Mode of transportation	**Total**
Car, truck, van as driver	121,400
Car, truck, van as passenger	19,830
Public transit	22,115
Walked	18,845
Bicycle	1,825
Motorcycle	240
Taxicab	520
Other method	1,640
Total - All modes	186,420

The commuting distance to work is shown in Table 11. About 80 percent of the people drive less than 20 km per day to work (one way), this analysis assumes that cars are driven about 40 km daily on weekdays to work.

Table 11: Commuting distance to work in Halifax (63)

Commuting distance (km)	Total
Less than 5 km	68,085
5 to 9.9 km	42,855
10 to 14.9 km	20,710
15 to 19.9 km	15,710
20 to 24.9 km	7,930
25 to 29.9 km	3,725
30 km or more	7,970
Median commuting distance	6.5
Total - All commuters	166,980

The average duration of a round trip between home and workplace for workers and for people travelling between 15 to 19 km is 60 minutes (or 30 minutes each way) (64).

4.3.2 BATTERY CAPACITY TO BE CHARGED AND BATTERY DEMAND

The annual driving distance per vehicle in Nova Scotia is about 20,044 km (61) which constitutes to a weekly average of about 386 km. This analysis assumes that cars are driven 40 km on weekdays, which leaves about 186 km for weekend driving (distributed equally as 93 km on Saturday and Sunday). A driving distance of 40 km/day means that the battery requires a 5.7 kWh charge every day and on the weekdays, for a driving distance of about 93 km the battery needs a charge of 13.3 kWh. The relationship between battery capacity and distance travelled is assumed to be linear (see Figure 9).

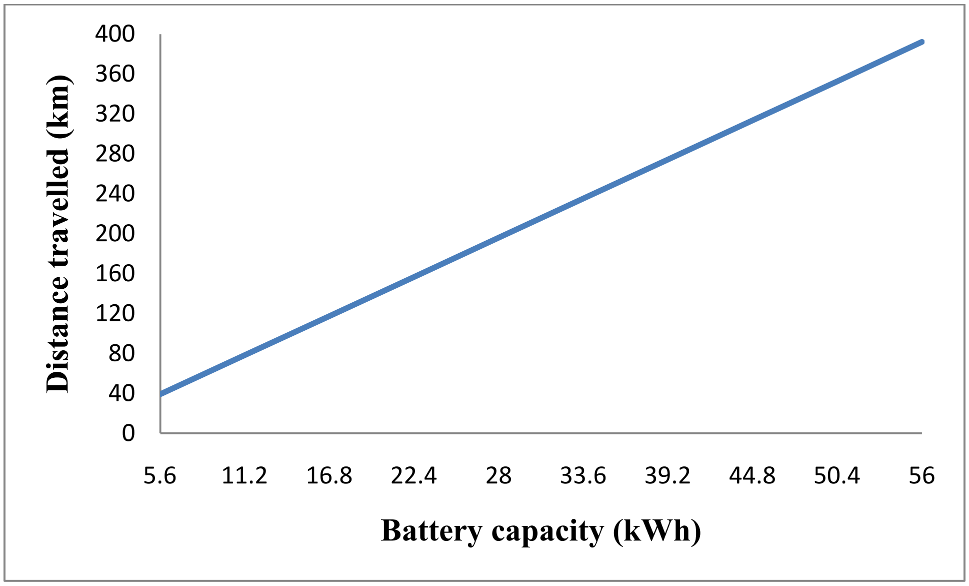

Figure 9: Distance travelled vs. Battery capacity

With a daily charge of 5.7 kWh and a weekend charge of 26.6 kWh, the vehicle has an annual battery demand of about 2878 kWh or 2.87 MWh. From section 3.3.1.2 the theoretical number of PEV batteries that can be charged with the wind for 2005-2006 was 3990 for the Overnight charging algorithm, and 8151 for the Anytime charging algorithm. The monthly battery demand is shown in Figure 10.

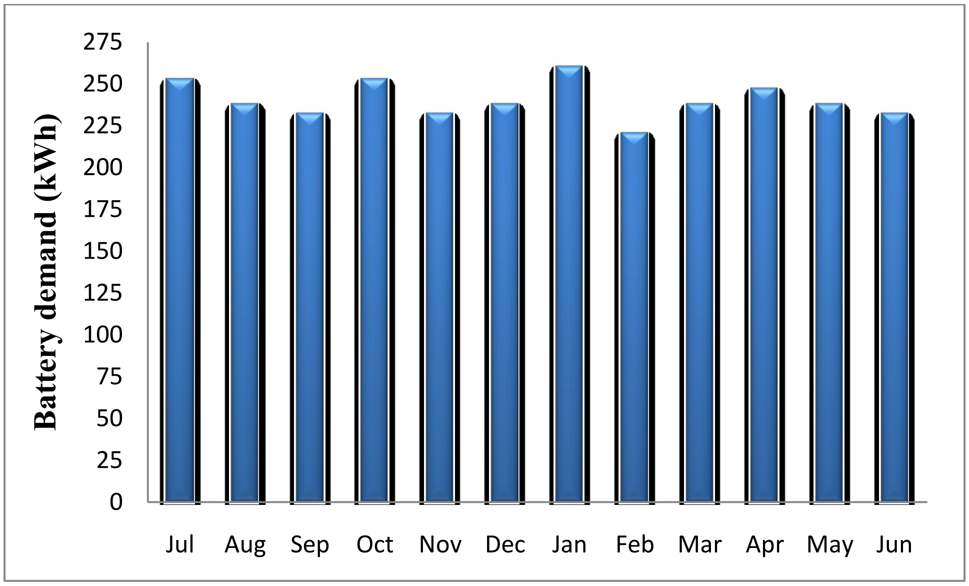

Figure 10: Monthly battery demand

4.3.3 CHARGER OPTIONS

The Tesla Roadster can be charged using the following options as shown in Table 12:

Table 12: Charger options (65)

Type of connector	Charging rate
High Power Wall Connector	16.8 kW
Universal Mobile Connector	9.6 kW
Spare Mobile Connector	1.8 kW

The PEVs used in this analysis are charged using the home connector with a charging rate of 16.8 kW. This charger allows variable charging and was chosen to better utilize the wind generated electricity whenever it is available.

4.4 ASSUMPTIONS

For these simulations, transmission, distribution, and heat loss from the ETS units in the off state and discharge from the PEVs batteries if not used, are not considered. During the analysis, if at any hour either one or more ETS units or PEVs goes to zero (empty state), it remains in that state until it is recharged by the wind-generated electricity. Even though some form of backup electricity is necessary to bridge the gap when wind is unavailable and some of the ETS units or PEVs, or both, have exhausted their energy, this algorithm does not take backup electricity from the grid or any other source into account but shows the backup energy required. The ETS and PEV units are considered to be fully charged at the beginning (first hour) of the analysis. Since it takes about 30 minutes each way to commute to work (64), for the purposes of the simulation it is assumed that it takes about an hour. The number of ETS units is rounded off to 2000 and the PEVs to 4000 for the Overnight charging and 8000 for the Anytime charging, from the values derived from 3.3.1.1 and 3.3.1.2.

4.5 OVERNIGHT CHARGING RESULTS

The simulations were carried out using the ETS-first and PEV-first charging algorithms. The results of these algorithms are discussed separately below.

4.5.1 ETS-first results

Figure 11 shows the results of running the ETS systems only. The surplus wind is the amount of wind energy available after heating has been met, while the backup energy is the electricity required from other sources to bridge the gap when wind is unavailable and the ETS units are fully-discharged (left axis). The space heating met is the percentage of space heating load that is satisfied by wind generated electricity (right axis).

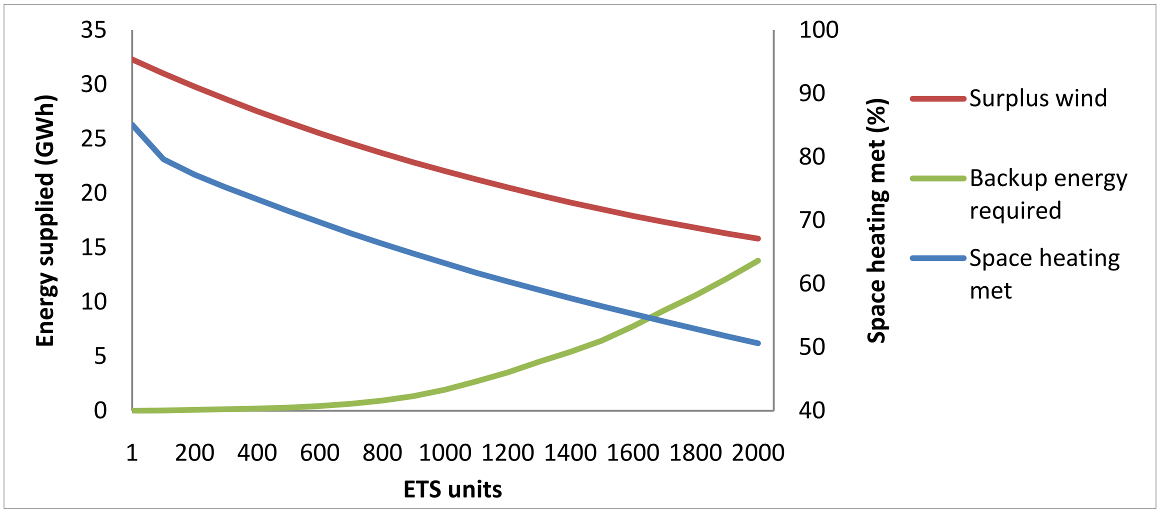

Figure 11: Surplus wind backup energy required and space heating met for ETS

The grid backup required increases gradually to about 5 GWh with 1300 ETS units and a total of about 14 GWh was required for 2000 ETS units. The percentage of space heating met by the wind was about 70% until 600 units and, for 2000 units, wind was able to satisfy almost 51% of the space heating demand. As the number of units increases, the need for backup from the grid also increases. Since wind might be available at times when space heating is not require or there may be excess after space heating needs are satisfied, the surplus wind-electricity available was about 16 GWh for 2000 ETS units.

The surplus wind-electricity can be used for other purposes, for example to charging plug-in electric vehicles during the overnight hours (11pm to 7am). Figure 12 shows the percentage of PEV battery demand met with surplus wind-electricity after satisfying the needs of the ETS units. The results range from 100% of PEV demand being met for 1600 PEVs up to about 300 ETS units, down to 36% of PEV demand for 6000 PEVs and 2000 ETS units.

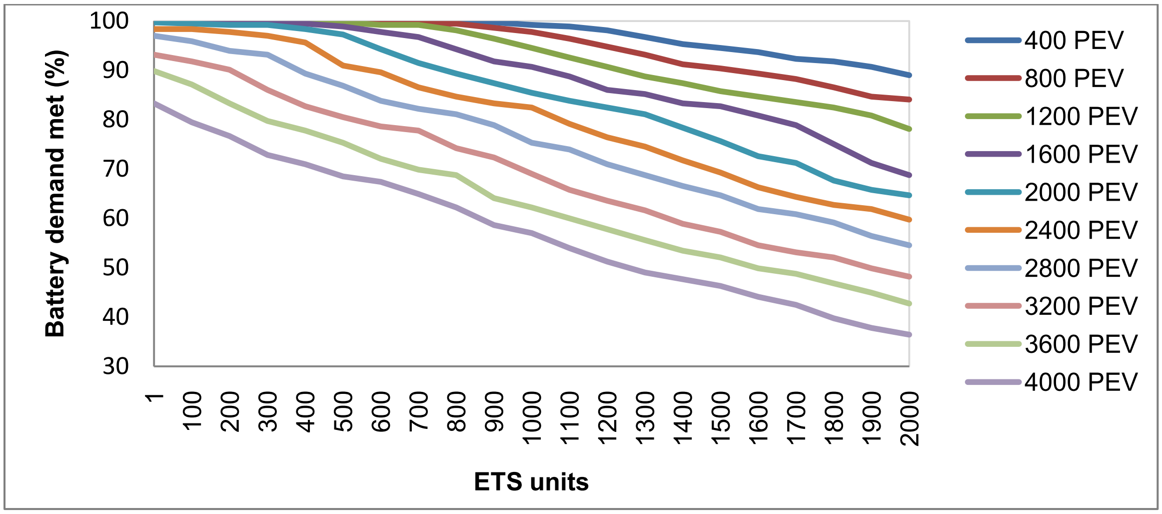

Figure 12: Battery demand met for PEVs when integrated with ETS

The amount of backup energy required for PEVs, when integrated with ETS units is presented in Figure 13. Here, for example, a single ETS unit integrated with up to 4000 PEVs requires a backup of about 0.9 GWh and, if 2000 ETS units were integrated with 3600 PEVs requires a backup of about 3 GWh and, if 2000 ETS were integrated with 4000 PEVs, a backup of about 4.5 GWh was required.

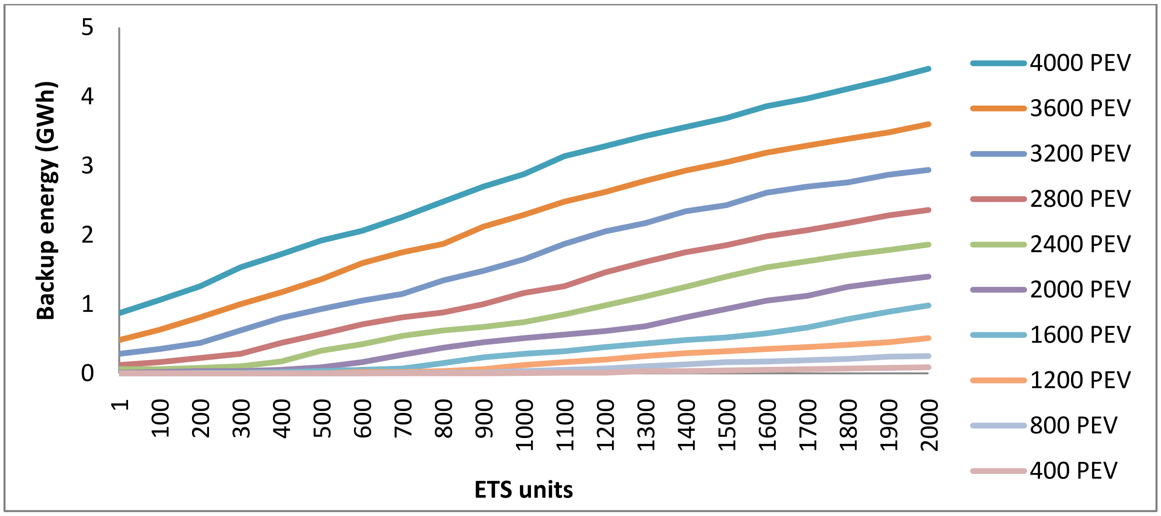

Figure 13: Backup energy required for PEVs when integrated with ETS

Figure 14 shows the excess wind available after charging the PEVs' batteries with surplus wind from the ETS units. A single ETS unit when integrated with 400 PEVs has excess wind of about 31GWh and when integrated with 4000 PEVs has excess wind of about 25 GWh. The excess wind drops to about 12 GWh for 2000 ETS and 4000 PEVs.

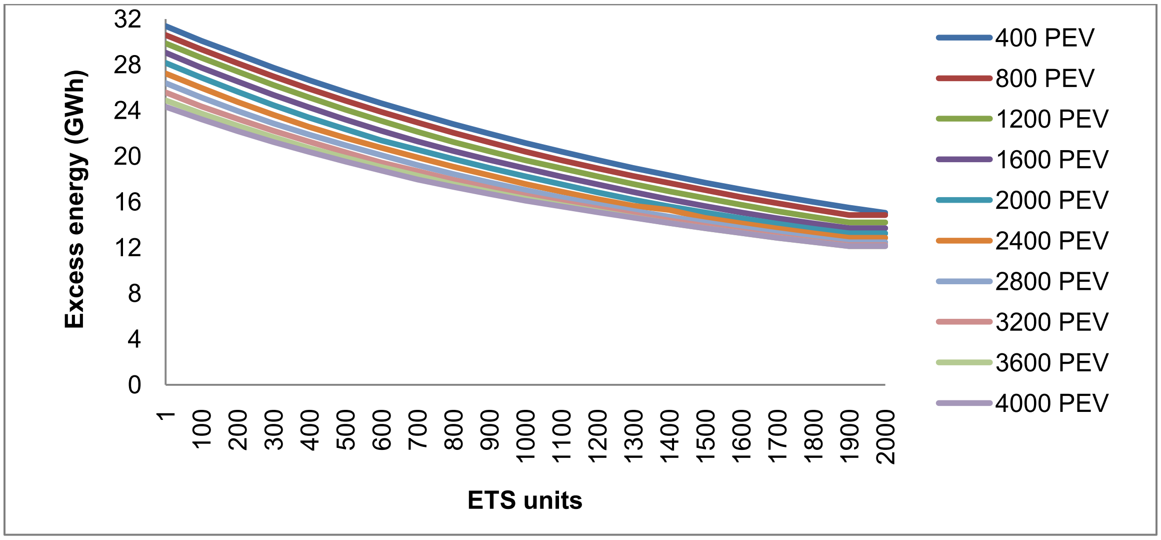

Figure 14: Excess wind electricity after charging the ETS and PEV units

4.5.2 PEVS-first results

The PEV-first results are shown in Figure 15 without supplying the surplus to the ETS units. Backup energy refers to the energy required to bridge the gap when wind is unavailable and the PEV battery needs to be charged (left axis). The surplus wind is the wind energy available after meeting the battery demand (left axis). The battery demand met is the percentage of battery demand met by wind electricity (right axis).

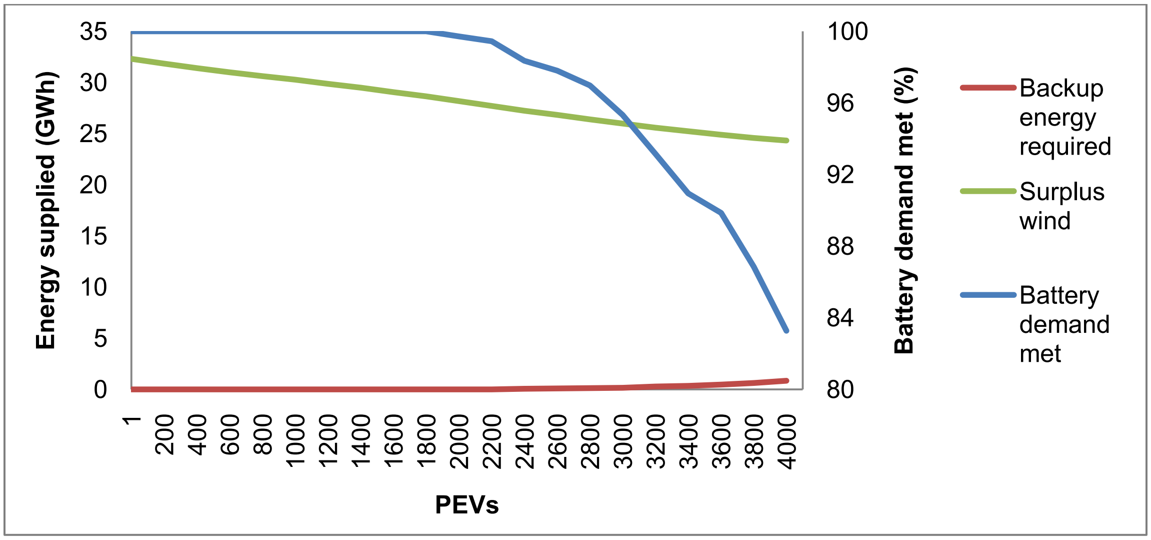

Figure 15: Backup, surplus wind, battery demand met for PEVs

Grid backup was not required and 100% of battery demand was met for up to 1800 PEVs. When supplying wind for 4000 PEVs, about 83% of the charging was met by the wind and the remainder came from backup electricity sources. At 4000 PEVs, about 0.9 GWh were supplied by backup and about 24 GWh was surplus.

Figure 16 shows the percentage of space heating met for ETS when integrated with PEVs. If one PEV is integrated with 2000 ETS units about 50% of the space heating demand is met. For 4000 PEVs and 2000 ETS the percentage of space heating met is about 38%.

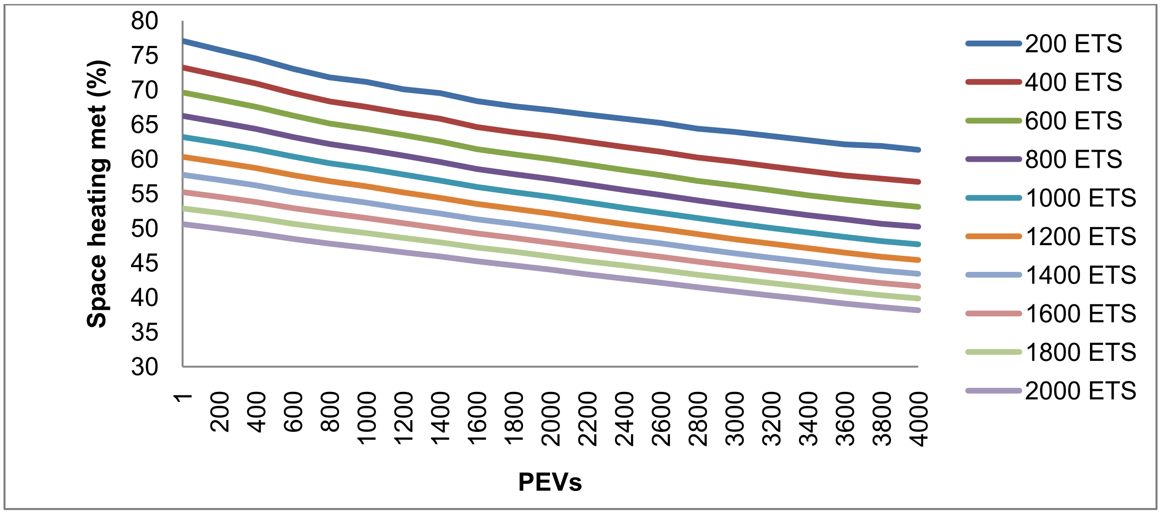

Figure 16: Space heating met for ETS units when integrated with PEVs

Figure 17 shows grid backup energy required when PEVs are integrated with ETS units. For a single PEV and 2000 ETS units, the amount of backup required is around 14GWh and if 4000 PEV and 2000 ETS units are integrated, the backup required increases to about 18.5 GWh.

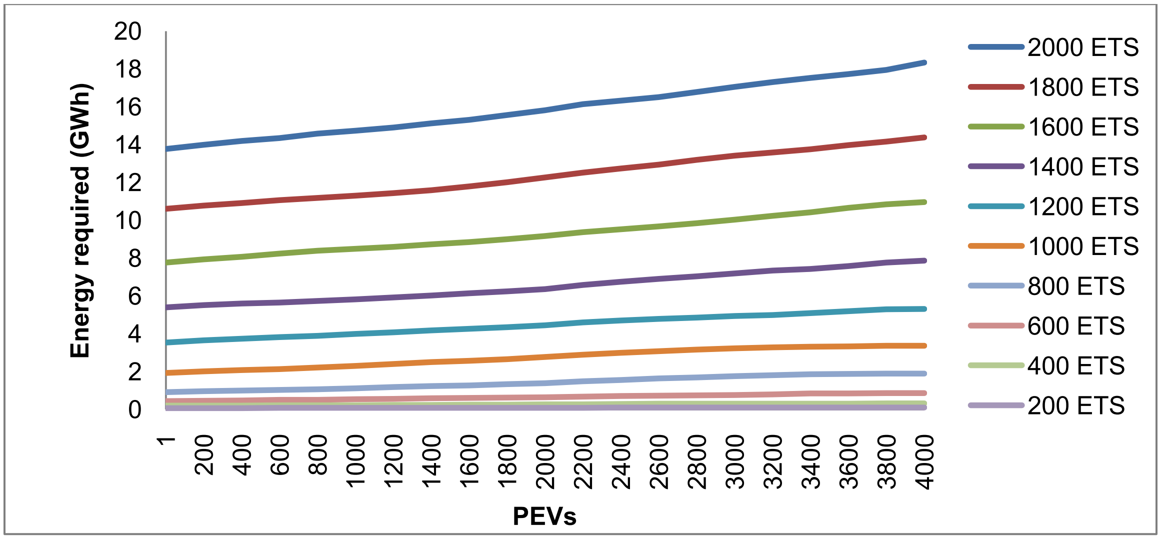

Figure 17: Backup energy required for ETS when integrated with PEVs

Figure 18 shows the amount of excess wind when the ETS units are charged with electricity surplus to the PEVs. For a single PEV and 200 ETS units the excess wind available is about 30 GWh and drops to about 16 GWh when integrated with 2000 ETS units and this drops to less than 12 GWh for 4000 PEVs and 2000 ETS units.

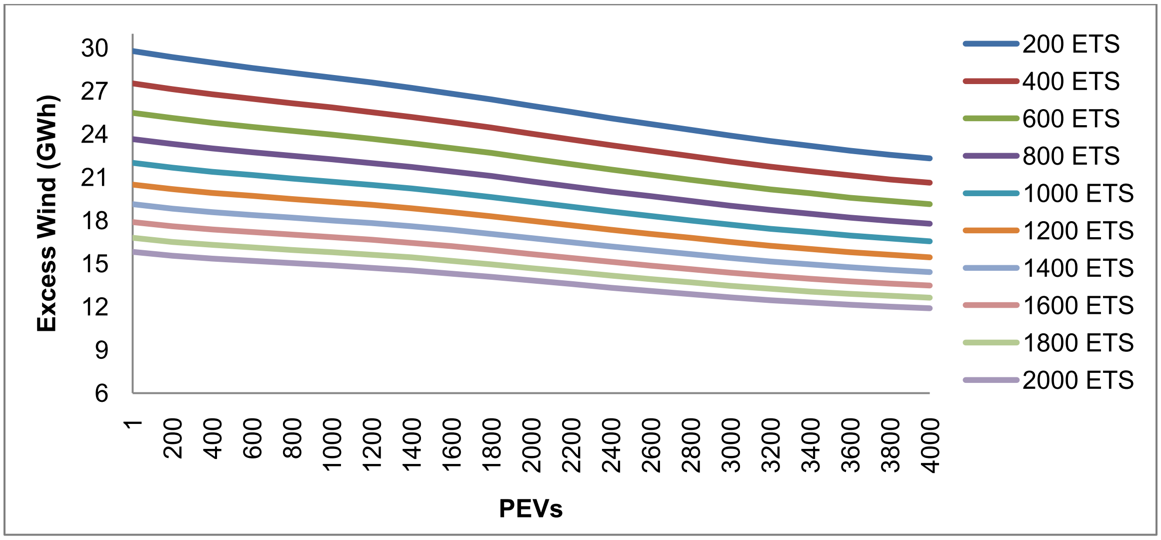

Figure 18: Excess wind electricity after charging the PEVs and ETS units.

4.6 ANYTIME CHARGING

The results are discussed in detail for the ETS-first and PEV-first algorithms.

4.6.1 ETS-first results

Figure 19 shows the results of running the ETS systems alone. The surplus wind is the amount of wind energy available after heating has been met (left axis), while the backup energy is the electricity required from other sources to bridge the gap when wind is unavailable and the ETS units are fully-discharged (left axis). The space heating met is the percentage of space heating load that is satisfied by wind generated electricity (right axis).

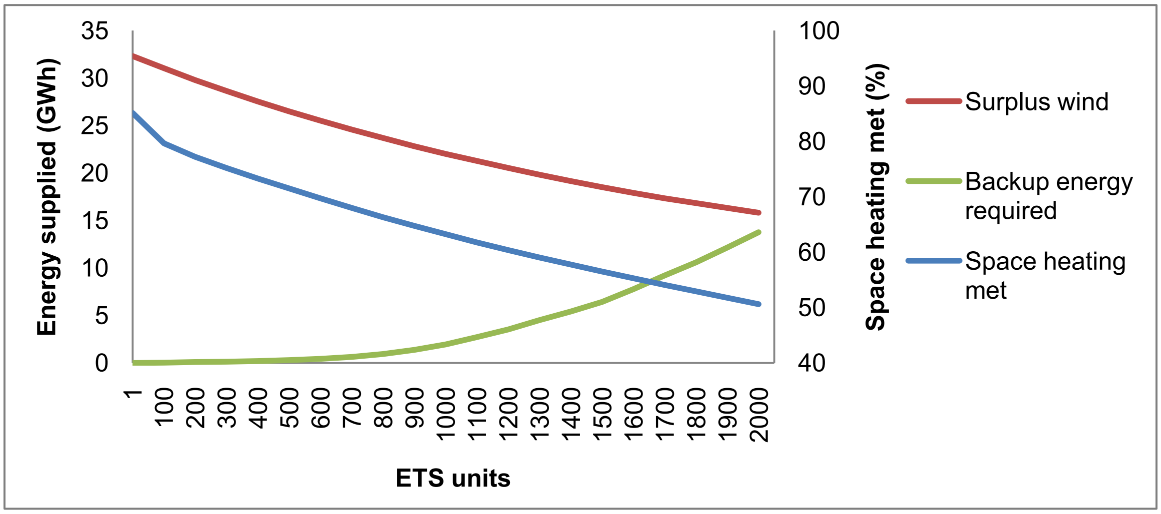

Figure 19: Backup energy, surplus wind and space heating met

The grid backup required increases gradually to about 5 GWh with 1300 ETS units and a total of about 14 GWh was required for 2000 ETS units. The percentage of space heating met by the wind was about 70% until 600 units and for 2000 units, wind was able to satisfy almost 51% of the demand for space heating. As the number of unit's increases, the need for backup from the grid also increases. Wind might be available at times when space heating is not required or there may be excess after space heating needs are satisfied, the surplus wind-electricity available was about 16 GWh for 2000 ETS units.

Figure 20 shows the battery demand met for the PEVs with the surplus wind available after satisfying the needs of the ETS units. If a single ETS unit was integrated with 8000 PEVs, 86% of the PEVs battery demand was met and if 2000 ETS were integrated with 800 PEVs, about 96% of the battery demand was met. For 2000 ETS and 8000 PEVs about 51% of the battery demand would be met.

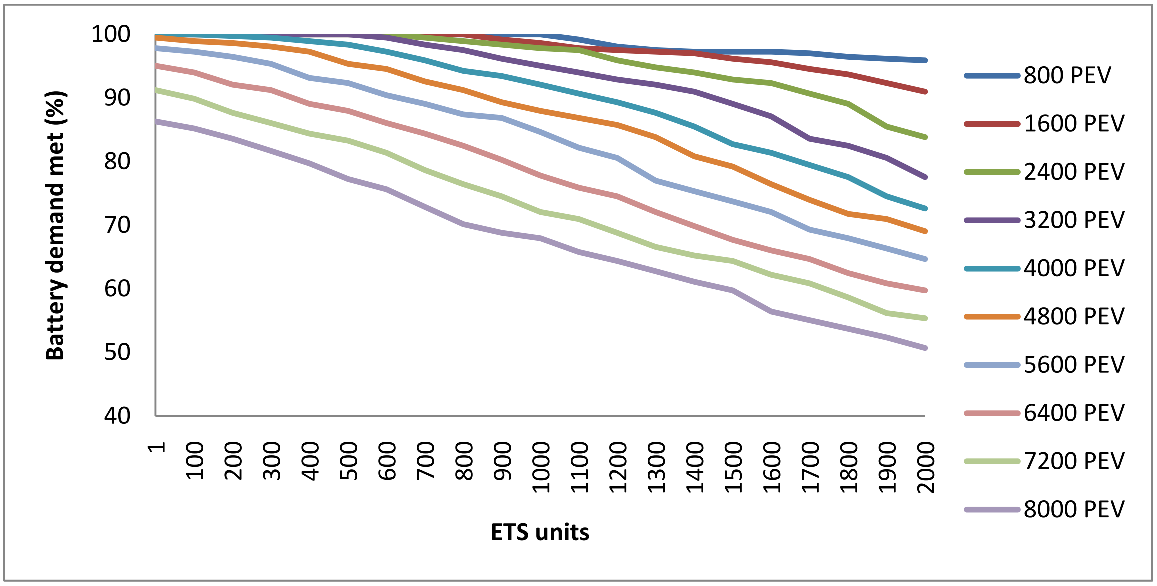

Figure 20: Battery demand met

The amount of backup energy required for PEVs when integrated with ETS units is presented in Figure 21. A single ETS unit integrated with 8000 PEVs requires backup of just over 1 GWh and if 2000 ETS units were integrated with 8000 PEVs a backup of about 6.2 GWh would be required.

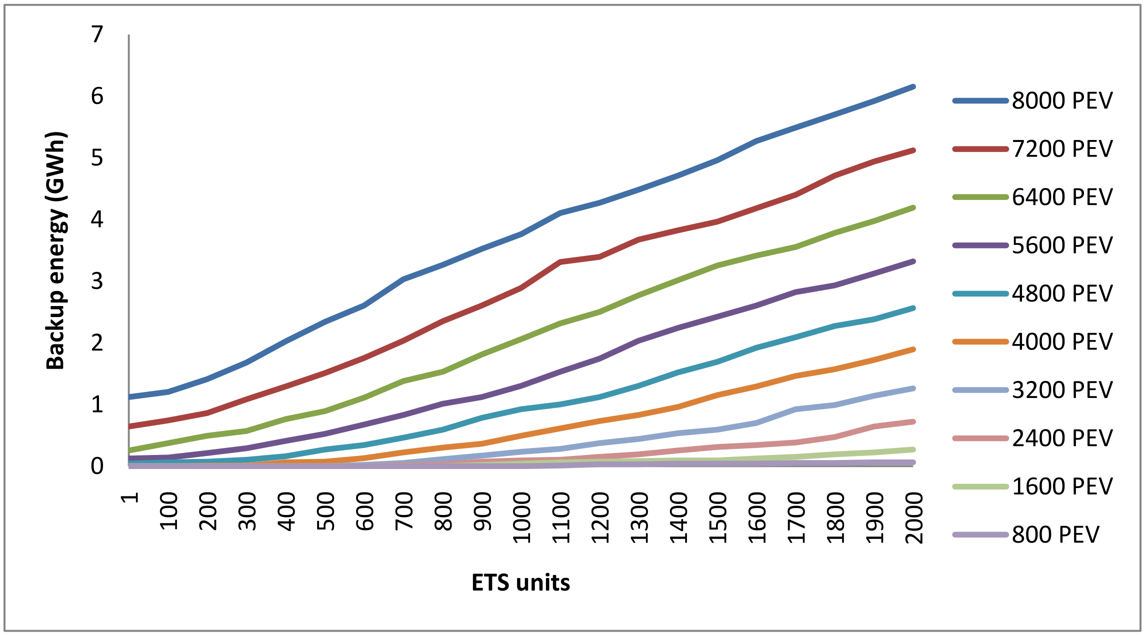

Figure 21: Backup energy required

Figure 22 shows the excess wind available after charging the PEVs batteries with surplus wind from the ETS units. A single ETS unit when integrated with 800 PEVs has excess wind close to 30 GWh and when integrated with 8000 PEVs has excess wind close to 14 GWh; this dropped to less than 6 GWh for 2000 ETS and 8000 PEVs.

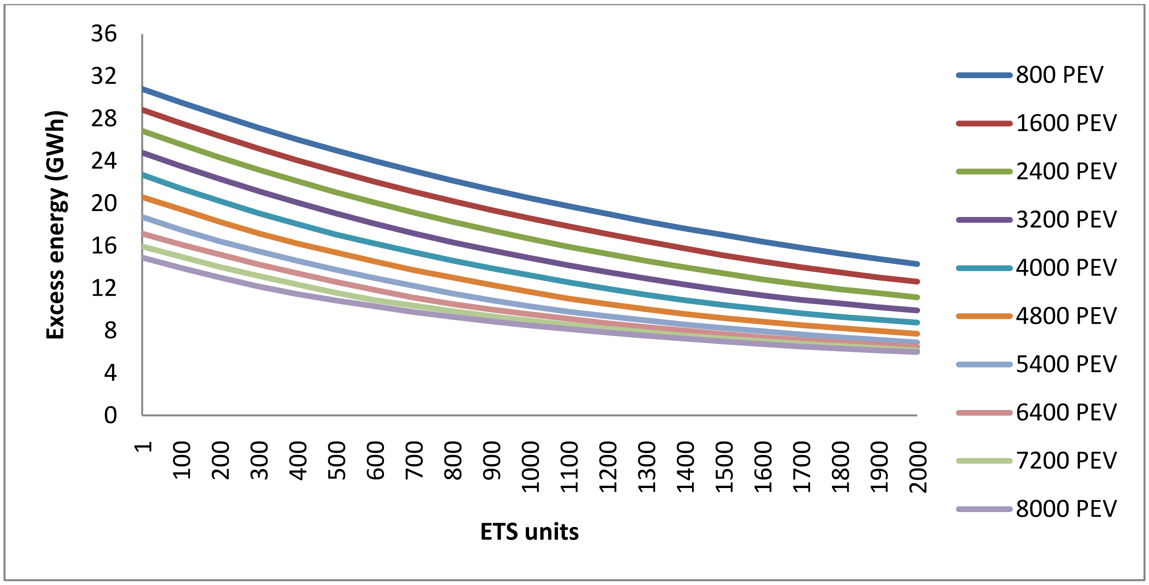

Figure 22: Excess wind electricity after charging the ETS and PEV units

4.6.2 PEVs-first results

The PEV-first results are shown in Figure 23 without supplying the surplus to the ETS units. Backup energy refers to energy required to bridge the gap when wind is unavailable and the PEV battery needs to be charged (left axis), surplus wind is the wind energy available after meeting the battery demand (left axis), and battery demand met is the demand for the PEV batteries that is satisfied by wind generated electricity (right axis).

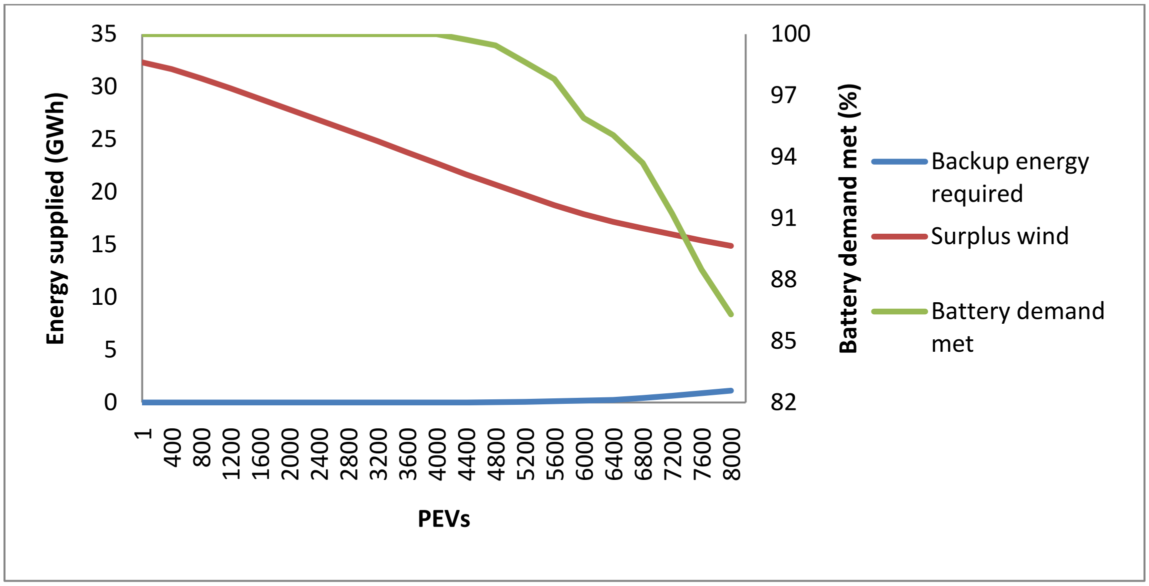

Figure 23: Surplus wind, backup energy required and battery demand met

Grid backup was not required and 100% of battery demand was met for up to 4400 PEVs. When supplying wind for 8000 PEVs, about 86% of the charging was met by the wind and the remainder came from backup electricity sources. At 8000 PEVs, about 1.2 GWh were supplied by backup and about 15 GWh was surplus.

Figure 24 shows the percentage of space heating met for ETS when integrated with PEVs. If one PEV is integrated with 2000 ETS units then about 51% of the space heating demand is met. For 8000 PEVs and 2000 ETS the percentage of space heating met is about 26%.

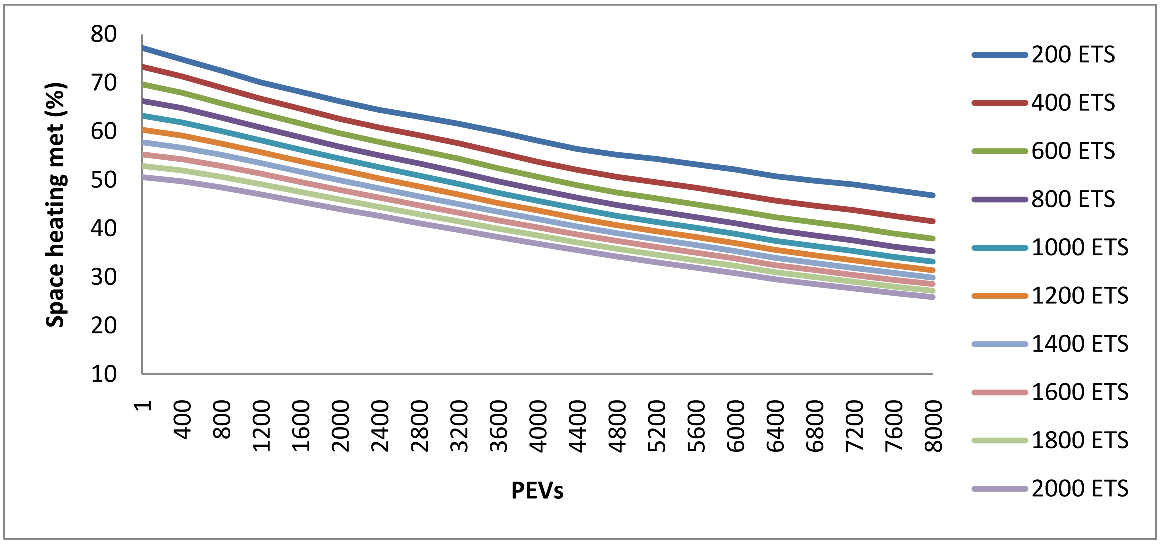

Figure 24: Space heating met

Figure 25 shows the backup energy required from the grid when including ETS units. For a single PEV and 2000 ETS units, the amount of backup required is about 14 GWh. If all 8000 PEVs and 2000 ETS units are connected, backup of about 24 GWh is required.

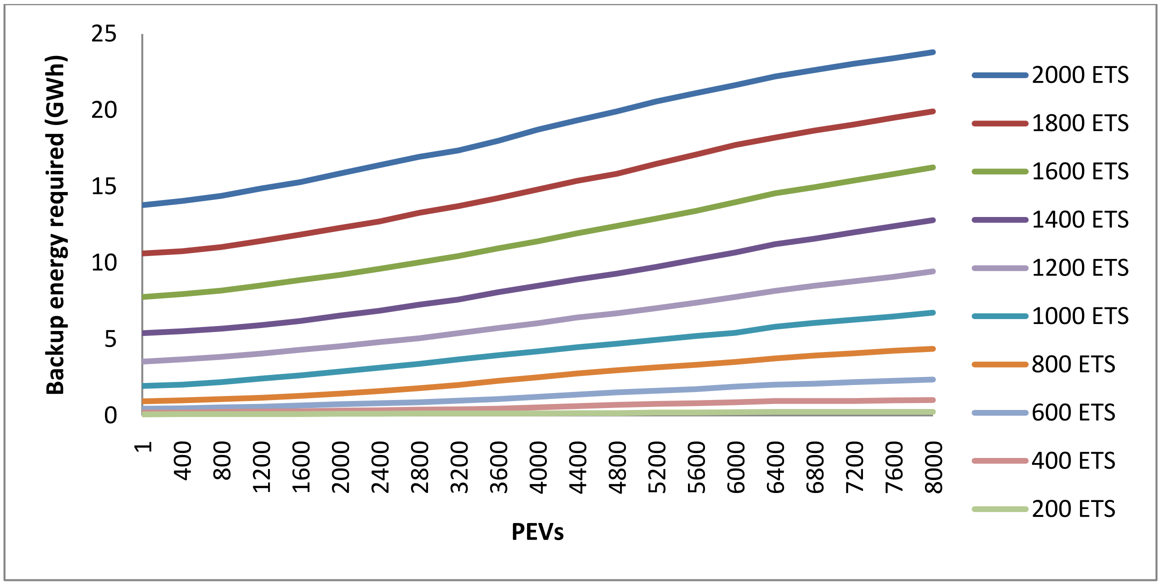

Figure 25: Backup energy required

Figure 26 shows the amount of excess wind when the ETS units are charged with electricity surplus to the PEVs. For a single PEV and 200 ETS units the excess wind available is close to 30 GWh and drops to about 16 GWh when integrated with 2000 ETS units. When 8000 PEVs and 2000 ETS units are integrated, the excess wind drops to 6.5 GWh.

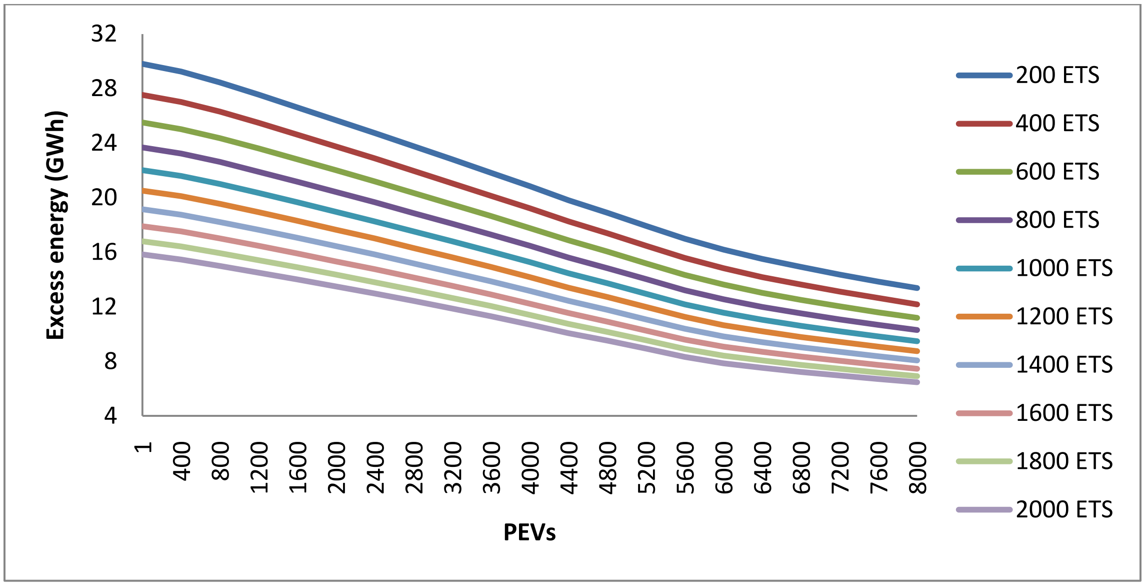

Figure 26: Excess wind electricity after charging the ETS and PEV units

4.7 DISCUSSION

The previous section showed how the two charging algorithms, ETS-first and PEV-first, could be used to meet the energy demand for space heating and electric vehicles. As the names suggest, when wind is available, it is first used to meet ETS (or PEV) demand and then, if there is a surplus, to meet PEV (or ETS) demand. Any excess is then available for use in other services or export.

4.7.1 LIMITED WIND-ELECTRICITY SUPPLY

Both the ETS and PEV store energy. In the case of ETS, stores up to 180 kWh as heat in ceramic bricks and in the PEV stores up to 56 kWh as electricity in batteries. Although an ETS unit stores more energy than a PEV, the daily demand for heat is such that in the most extreme conditions, the ETS could be called upon to supply 10 kWh every hour, whereas the PEV uses about 5.7 kWh per day on the weekdays and about 13.3 kWh on weekends. The difference in storage capacity and daily demand are such that the PEV is able to withstand lengthy periods without being recharged. The same cannot be said for the ETS, which is normally recharged every 24 hours or less (typically between 23h and 7h) during the heating season.

In addition, an ETS unit can be charged throughout the day when there is electricity available from the wind, whereas a PEV can only be charged between 23h and 7h (Overnight charging) and for 21 hours daily (Anytime charging). These differences are highlighted in the following figures, which show the effect of lengthy periods of limited wind between 13 February 2006 and 28 February 2006.

4.7.1.1 *EFFECT ON ETS*

The effect on the state of the ETS units during periods of cold temperatures and a decrease in wind supply is shown in Figure 27. In this example, temperatures averaged -15.6°C between hours 149 and 160 and -11.8°C between hours 289 and 361 (from X axis of the figure). The limited wind brought the state of charge of a single ETS to zero between hours 252 and 274 (from X axis of the figure), at which point a small amount of wind allowed the ETS to recover. However, when 2000 ETS units are considered, the cold and lack of wind meant that whatever wind was available, it went straight to heating and not to recharging the units. The results are for ETS-first during this time, the PEVs were not recharged.

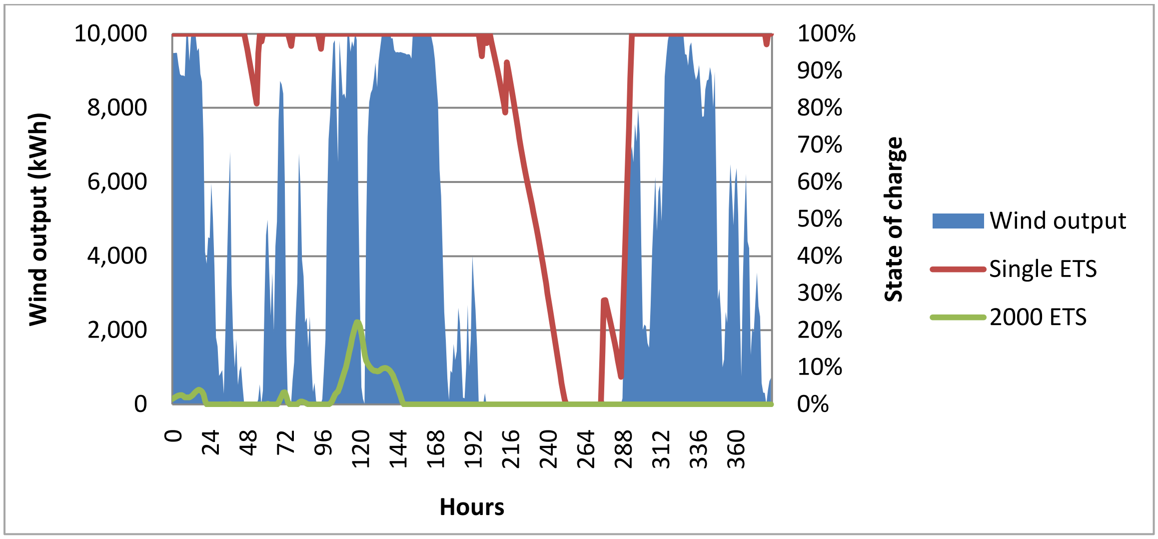

Figure 27: Effect of limited wind availability on ETS units

4.7.1.2 *EFFECT ON PEVs*

The total distance traveled each day and the size of the batteries means that PEVs can go for extended periods without recharging. This is illustrated in Figure 28, which shows the state of charge of a single PEV and 4000 PEVs when using Overnight charging. Unlike the ETS units, the batteries allow the PEVs to bridge the periods of no wind easily. Similarly, the size of the batteries and the recharging rate allows all the batteries to benefit from the available wind, but as the number of PEVs increase so does the demand and irrespective of the available wind the PEVs begin to suffer.

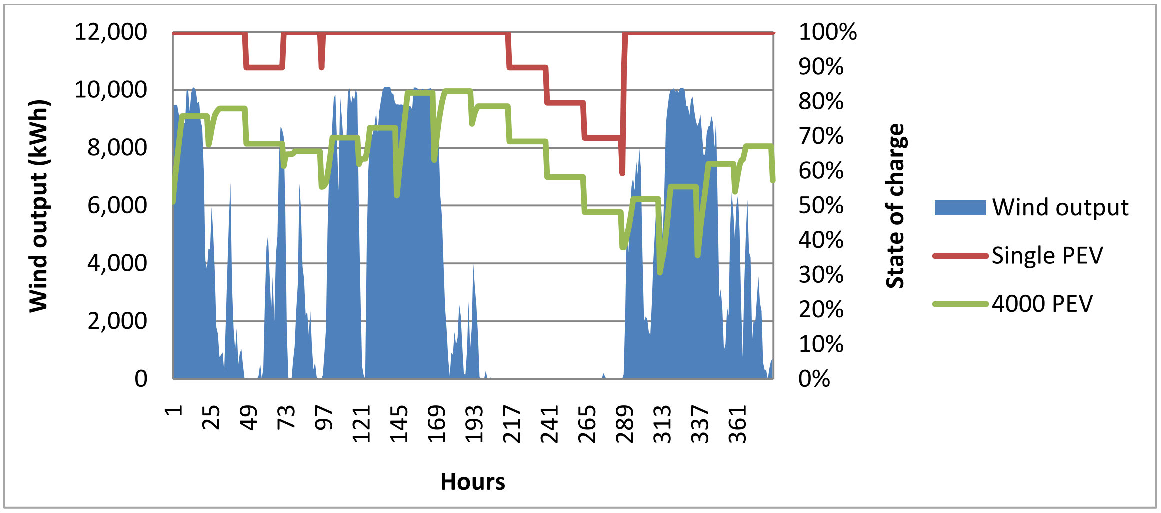

Figure 28: Effect of limited wind availability on PEVs (Overnight charging)

On the other hand, with Anytime charging, the PEVs are able to handle the lack of wind supply slightly better. The reason being that more wind is available as the PEVs are charged for a longer duration of time. Also since the distance travelled is the same, the additional charging time helps the PEVs reach full capacity around hours 96 and 130 as shown in Figure 29 for 8000 PEVs. As the number of PEVs increase they suffer as the difference between demand and supply increases.

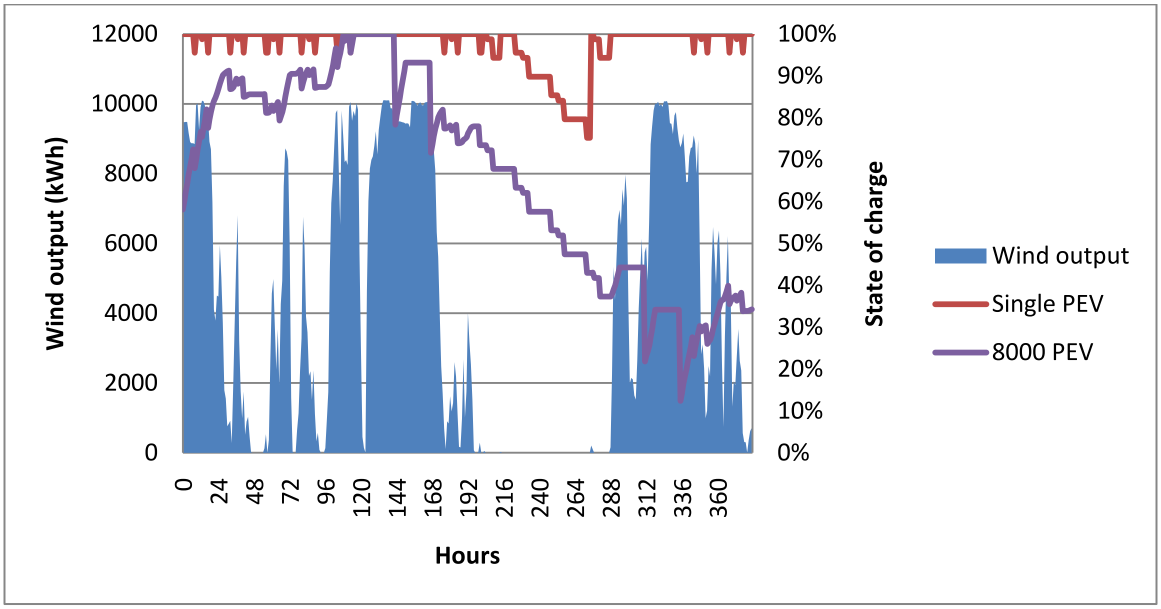

Figure 29: Effect of limited wind availability on PEVs (Anytime charging)

Regardless of whether ETS-first or PEV-first is adopted, the amount of excess electricity during the 2005-06 simulation for the maximum number of ETS units and PEVs was just under 12 GWh for PEV-first and just over 12 GWh for ETS-first algorithm for the Overnight charging algorithm and just under 6 GWh for ETS-first algorithm and around 6.5 GWh for PEV-first algorithm for the Anytime charging algorithm. About 20 GWh and 26 GWh of energy previously required for space heating and transportation was displaced, respectively. However, this is somewhat misleading as it masks the amount of electricity required for backup. When using ETS-first, the maximum backup required were about 18 GWh and 20 GWh, while with PEV-first, the maximum backup required was around 19 GWh and 25 GWh for the Overnight charging algorithm and the Anytime charging algorithm, respectively.

4.8 SUMMARY

In this chapter residential and transport sectors of Halifax were used to establish how wind energy could be utilized as a case study to demonstrate the algorithms developed in this research.

A brief overview of the wind resource available, space heating demand of the residential sector, mode of transportation and distance commuted to work was discussed for Halifax. The wind integration was done and the algorithms were applied and the results of simulations were graphically represented for ease of understanding and comparison

Chapter 5 CONCLUSIONS

Canada is a world leader in the production and use of electricity from renewable resources. With renewable energy sources currently contributing about 16 % of Canada's total primary energy supply with moving water (hydro) providing about 59% of Canada's electricity (66). As investments in new renewable technologies are increasing every year, if renewable sources of energy such as wind, solar, and tidal are to meet either some or most of the space heating and PEV`s demand, there needs to be a change in the way it is presently being used.

5.1 MOTIVATION

In 2007, the residential sector accounted for 16% (67) and the transportation sector accounted for 29% of Canada's total secondary energy use (68), totalling to 45%. Motivated by the 45% of secondary energy usage, the objective of thesis was develop charging algorithms that could be applied to the residential sector (for space heating) and the transportation sector (for charging electric car batteries) and help address energy security by using domestic sources of energy like wind-generated electricity. Using renewable sources of energy would also help reduce GHG emissions and conserve natural resources.

5.2 FINDINGS

Both the algorithms ETS-first and PEV-first were carried out for the city of Halifax and the findings were as follows:

1. Overnight charging algorithm: for a combination of 2000 ETS and 4000 PEVs, both the algorithms indicated almost similar results with respect to excess wind. However, there was a difference of 1 GWh with respect to backup energy required as shown in Table 13 below. This difference of 1 GWh was because the large demand for space heating was met with the surplus wind (wind available after battery charging). For the ETS-first algorithm the percentage of space heating met is more compared to PEV-

first because the ETS units are charged first with the wind and similarly in the PEV-first algorithm the percentage of battery demand met is more. The PEV-first algorithm consumed 0.3 GWh more available wind and required 1 GWh less backup energy compared to the ETS-first algorithm.

Table 13: Comparison of the algorithms for Overnight charging algorithm

Specifics	**ETS-first algorithm**	**PEV-first algorithm**
Space heating met (%)	51	38
Battery demand met (%)	36	83
Backup energy (GWh)	18.2	19.2
Excess wind (GWh)	12.1	11.9

2. Overnight charging algorithm: for the ETS-first algorithm, 600 ETS units and 4000 PEVs integrated, would result in satisfying 70% space heating and 67% battery demand. The PEV-first algorithm, 2000 PEVs and 600 ETS units integrated, would result in satisfying 100% battery demand and 60% space heating needs.
3. Anytime charging algorithm: for a combination of 2000 ETS and 8000 PEVs, both the algorithms worked with similar amounts of excess wind remaining. The ETS-first algorithm had around 6 GWh and PEV-first 6.5 GWh, the PEV-first algorithm required about 6 GWh more backup energy as compared to ETS-first algorithm as shown in Table 14 below. The ETS-first algorithm consumed 0.5 GWh more available wind and required almost 6 GWh less backup energy compared to PEV-first algorithm.

Table 14: Comparison of the algorithms for Anytime charging algorithm

Specifics	ETS-first algorithm	PEV-first algorithm
Space heating met (%)	51	26
Battery demand met (%)	51	86
Backup energy (GWh)	19.2	24.9
Excess wind (GWh)	6	6.5

4. In the Anytime charging algorithm, for the ETS-first algorithm if 600 ETS units and 8000 PEVs integrated would result in satisfying 70% space heating and 76% battery demand. The PEV-first algorithm if 2000 PEVs and 600 ETS units integrated would result in satisfying 100% battery demand and 60% space heating needs.
5. About 20 GWh and 26 GWh of energy previously required for space heating and transportation was displaced using the Overnight and Anytime charging algorithms, respectively.
6. Overnight charging algorithm consumed about 62% of the wind-electricity and exhibited similar levels of excess wind for both the algorithms. Anytime charging algorithm consumed about 81% of the wind-electricity and exhibited similar levels of excess wind for both the algorithms.

5.3 OBSERVATIONS AND RECOMMENDATIONS

The following observations and recommendations were made from the results of this research:

- For some consumers or utility providers, space heating may be more important than charging their PEVs and hence the algorithm must be chosen based on priority of requirements or service.
- As the number of units (ETS/PEV) increase, due to increase in demand and the limited supply of wind, the percentage of demand met decreases. As a result, there is an increase in backup energy required.

- For a single ETS unit, 100% of the demand could not be met, even if there was more wind-generated electricity available than space heating demand. 100% of the demand was not met because the demand and supply did not coincide all the time. There were times when space heating demand was needed but wind supply was unavailable and other times when there was more wind supply than the demand.
- Although the ETS has a larger storage capacity compared to the PEV battery, the daily space heating demand required was more compared to the daily driving requirement and hence could not handle long periods of limited supplies of wind.
- Due to the short daily driving distance which constitutes about 10% of battery capacity, the PEVs were able to handle the intermittent wind much better than the ETS units.

5.4 PUBLICATIONS

Part of the work done in this thesis was presented and published at the International Green Energy Conference (IGEC V) held in Waterloo, Ontario in June 2010. Subsequently, the International Journal of Energy Research (IJER) invited my supervisor and the present author to submit a revised version of the paper. A submission was made in October 2010.

5.5 FUTURE WORK

This thesis can be extended with the following future work:

- This thesis has not examined the technology required to test the algorithm, i.e., related electrical, electronic equipment and software for recognizing the services connected at any instant of time. However, there is a need to design and build a system which will recognize number of ETS and PEVs online, state of their charge, energy required to charge them, wind energy available at any instant of time or for the hour, so that it could help the algorithm take the necessary action.
- More simulations can be done using the PEV batteries as a potential backup energy source and supply to the ETS units when they are in need of electricity and wind is

unavailable. Using the PEV battery as a backup source could help reduce the backup energy required and further increase the percentage of space heating demand with wind-generated electricity.

- From the results of the simulations, it would appear that actual tests would be warranted.
- The algorithms can be modified and used with real-time heating and driving data.

BIBLIOGRAPHY

1. **Bernstein et al.** *Climate Change 2007: Synthesis Report.* s.l. : IPCC, 2007.

2. **NRDC.** NRDC: Ocean Acidification: The Other CO2 Problem. *Natural Resources Defense Council.* [Online] 7 19, 2009. [Cited: 05 10, 2010.] http://www.nrdc.org/oceans/acidification/.

3. **International Energy Agency.** Energy security, Growth and Sustainability through Co-operation and Outreach. *International Energy Agency.* [Online] 2009. [Cited: September 25, 2009.] http://www.iea.org/Textbase/subjectqueries/keyresult.asp?KEYWORD_ID=4103.

4. **Hughes, Larry.** Meeting residential space heating demand with wind-generated electricity. *Renewable Energy.* November 2009a, p. doi:10.1016/j.renene.2009.11.014.

5. **EIA.** International energy data and analysis. *Energy Information Administration* . [Online] 06 2008. [Cited: 01 25, 2010.] http://www.eia.doe.gov/iea/elec.html.

6. **UNEP.** *Global Trends in Sustainable Energy Investment 2009.* s.l. : UNEP, 2009.

7. **Maritime Electric.** Renewable Energy. *Maritime Electric.* [Online] 2009. [Cited: 01 15, 2010.] http://www.maritimeelectric.com/environment/env_energy.asp.

8. **Millais, Corin.** *Popularity and Politics.* s.l. : EWEA, n.d.

9. **E.ON.** *Wind Report 2005.* Bayreuth, Germany : E.ON Netz GmbH, 2005.

10. **Luickx, Patrick J, Delarue, Erik D and D'haeseleer, William D.** Considerations on the backup of wind power: Operational backup. *Applied Energy.* September 2008, Vol. 85, 9, pp. 787-799.

11. **ENTSOE.** Nordel Annual Report 2008. *European Network of Transmission System Operators for Electricity.* [Online] n.d. [Cited: March 22, 2010.] http://www.entsoe.eu/index.php?id=66.

12. **Lund, Henrick and Mathiesen, B.** Energy system analysis of 100% renewable energy systems—The case of Denmark in years 2030 and 2050. *Energy.* 2009, Vol. 34, DOI: 10.1016/j.energy.2008.04.003.

13. **NRCan.** Residential Sector Canada Table 2: Secondary Energy Use and GHG Emissions by End-Use. *Natural Resources Canada.* [Online] 12 01, 2009. [Cited: 01 18, 2010.] http://oee.nrcan.gc.ca/corporate/statistics/neud/dpa/tablestrends2/res_ca_2_e_4.cfm?attr=0.

14. **Hughes, Larry.** Meeting residential space heating demand with wind-generated electricity. *Renewable Energy.* November 2009, p. doi:10.1016/j.renene.2009.11.014.

15. **Hughes, Larry, et al.** A Study of Wind Energy Use for Space Heating in Prince Edward Island. 2006, p. 16.

16. **Plug in America.** Plug in America. *Plug in America.* [Online] 2009. [Cited: 06 23, 2010.] http://www.pluginamerica.org/what-are-plugins.shtm.

17. **Barthelmie, R J,. and Pryor, S C.** Climate change impacts on wind energy: A review. 2010, pp. 430-437.

18. **IEA.** International Energy Agency - Renewable Energy. *IEA.* [Online] 2010. [Cited: 11 05, 2010.] http://www.iea.org/subjectqueries/keyresult.asp?KEYWORD_ID=4116.

19. **NRCan.** Energy Sector: Renewable Energy: About Renewable Energy. *Natural Resources Canada.* [Online] 01 2009. [Cited: 11 09, 2010.] http://nrcan.gc.ca/eneene/renren/aboaprren-eng.php#tphp.

20. **Manitoba hydro.** Manitoba hydro - About us. *Manitoba hydro.* [Online] n.d. [Cited: 10 30, 2010.] http://www.hydro.mb.ca/corporate/about_us.shtml?WT.mc_id=2102.

21. **Hydro Quebec.** Hydro-Québec Production. *Hydro Quebec.* [Online] 2010. [Cited: 10 30, 2010.] http://www.hydroquebec.com/generation/index.html.

22. **Nova Scotia Power.** NS Power Facts and History. *Nova Scotia Power.* [Online] 2010. [Cited: 10 30, 2010.] http://www.nspower.ca/en/home/aboutnspi/nspfacts/default.aspx.

23. **Nova Scotia Power.** Renewable energy. *Nova Scotia Power.* [Online] 2009. [Cited: 09 12, 2010.] http://www.nspower.ca/en/home/environment/renewableenergy/default.aspx.

24. **Nova Scotia Power.** Wind Turbine Map. *Nova Scotia Power.* [Online] 2010. [Cited: 11 02, 2010.] http://www.nspower.ca/en/home/environment/renewableenergy/wind/map.aspx.

25. **Government of Nova Scotia.** Nova Scotia Department of Energy Renewable Energy Standard. *Government of Nova Scotia.* [Online] 10 09, 2009. [Cited: 11 09, 2010.] http://www.gov.ns.ca/energy/renewables/renewable-energy-standard/.

26. **Georgilakis, Pavlos S.** Technical challenges associated with the integration of wind power into power systems. April 2008, Vol. 12, 3, pp. 852-863.

27. **El-Saadany, E F. and Albadi, M H.** Overview of wind power intermittency impacts on power systems. 2009, p. 6.

28. **Rosenbloom, Eric.** The use of wind energy should not be increased. [book auth.] Stuart A Kallen. *What energy sources should be pursued?* Detroit : Greenhaven Press, 2005.

29. **Piwko, R., et al.** Wind energy delivery issues [transmission planning and competitive electricity market operation]. 2005, pp. 47 - 56.

30. **Negrete-Pincetic, M., et al.** Emerging issues due to the integration of wind power in competitive electricity markets. 2010, pp. 45-50.

31. **Etezadi-Amoli, M., Choma, K. and Ahmad, J.** An investigation of select barriers and solutions for renewable energy deployment. 2006, p. 8 pp.

32. **Kiviluoma, Juha. and Meibom, Peter.** Influence of wind power, plug-in electric vehicles, and heat storages on power system investments. 2010, pp. 1244–1255.

33. **Nguyen, Khanh Q.** Impacts of wind power generation and CO2 emission constraints on the future choice of fuels and technologies in the power sector of Vietnam. 2007, pp. 2305–2312.

34. **Holttinen, Hannele, et al.** Impacts of large amounts of wind power on design and operation of power systems, results of IEA collaboration. *Wnd Energy.* 2010.

35. **Natural Resources Canada's Office of Energy Efficiency.** *Heating with Electricity.* Ottawa : Office of Energy Efficiency Natural Resources Canada, 2003.

36. **Steffes, Paul.** *Wind Assisted Heating.* North Dakota : steffes corporation, 2008.

37. **Nova Scotia Power.** Domestic Service Time-Of-Day Tariff (Optional). *Nova Scotia Power.* [Online] 2010. [Cited: 09 15, 2010.] http://www.nspower.ca/en/home/aboutnspi/ratesandregulations/electricityrates/domesticservicetimeofdaytarriffoptional.aspx.

38. **Steffes, Paul.** *Wind Assisted Heating.* Dickinson : Steffes Corporation, 2008.

39. **Electric Auto Association.** *Electric Vehicle History.* s.l. : Electric Auto Association, 2005.

40. **Brown, Stephen,, Pyke, David. and Steenhof, Paul.** Electric vehicles: The role and importance of standards in an emerging market. 2010, pp. 3797-3806.

41. **Tesla Motors.** Tesla Roadster Technology and Innovations. *Tesla Motors.* [Online] n.d. [Cited: 10 08, 2010.] http://www.teslamotors.com/roadster/technology.

42. **NRCan.** Residentail Sector Canada Table 2: Secondary Energy Use and GHG Emissions by End-Use. *NRCan.* [Online] 12 01, 2009. [Cited: 10 23, 2010.] http://oee.nrcan-rncan.gc.ca/corporate/statistics/neud/dpa/tablestrends2/res_ca_2_e_4.cfm?attr=0.

43. **NRCan.** Residential Sector Canada Table 7: Space Heating Secondary Energy Use and GHG Emissions by Energy Source. *NRCan.* [Online] 12 01, 2009. [Cited: 10 23, 2010.]

http://oee.nrcan.gc.ca/corporate/statistics/neud/dpa/tablestrends2/res_ca_7_e_4.cfm?attr=0.

44. **Blackwell, Richard.** Summerside stores the wind. *Globe and Mail.* s.l., Canada : Globe and Mail, October 13, 2010.

45. **Lindly, Jay K. and Haskew, Tim A.** Impact of electric vehicles on electric power generation and global environmental change. 2002, pp. 291-302.

46. **Peterson, Scott B., Whitacre, Scott B, and Apt, Scott B.** The economics of using plug-in hybrid electric vehicle battery packs for grid storage. 2010, pp. 2377–2384.

47. **Perujo, Adolfo. and Ciuffo, Biagio.** The introduction of electric vehicles in the private fleet: Potential impact on the electric supply system and on the environment. A case study for the Province of Milan, Italy. 2010, pp. 4549–4561.

48. **Aksoy, Levent.** The Impact of Electric Vehicles on Electricity Consumption. 2009, pp. I-357 - I-359.

49. **Hadley, Stanton W and Tsvetkova, Alexandra A.** Potential Impacts of Plug-in Hybrid Electric Vehicles on Regional Power Generation. 2009, pp. 56-68.

50. **Dashora, Yogesh, et al.** The PHEV Charging Infrastructure Planning. 2010, Vol. 11, 2, pp. DOI: 10.2202/1553-779X.2482.

51. **Tesla Motors.** Charging demo & FAQ. *Tesla Motors.* [Online] 2010. [Cited: 01 25, 2010.] http://www.teslamotors.com/electric/charging_demo.php?displayall=1.

52. **Satman, A. and Yalcinkaya, N.** Heating and cooling degree-hours for Turkey. 1999, Vol. 24, 10, pp. 833-840.

53. **Power Advisory LLC.** Study finds significant opportunity for Atlantic Canada wind exports to U.S. . *CANWEA.* [Online] 2009. [Cited: 01 15, 2010.] http://www.canwea.ca/media/release/release_e.php?newsId=60.

54. **Canwea.** North Cape Wind farm. *Canadian Wind Energy Association.* [Online] 2008. [Cited: 02 17, 2010.] http://www.canwea.ca/featuredWindFarm_e.php?farmId=43.

55. **Statistics Canada.** Private households by structural type of dwelling, by province and territory (2006 Census) . *Statistics Canada.* [Online] October 12, 2007. [Cited: June 12, 2009.] http://www40.statcan.ca/l01/cst01/famil55a-eng.htm.

56. **Environment Canada.** National Climate Data and Information Archive. *Environment Canada.* [Online] 2009. [Cited: 09 15, 2009.] http://climate.weatheroffice.gc.ca/climateData/canada_e.html.

57. **Steffes corporation.** *Comfort Plus.* North Dakota : Steffes corporation, n.d.

58. **Hughes, Larry.** The technical potential for off-peak electricity to servce as backup in wind-electric thermal storage systems. *International Journal of Green Energy.* 2010.

59. **Tesla Motors.** Roadster Features and Specifications . *Tesla Motors.* [Online] 2010. [Cited: 010 27, 2010.] http://www.teslamotors.com/roadster/specs.

60. **Transport Canada.** Road Transportation . *Transport Canada.* [Online] 05 18, 2010. [Cited: 06 16, 2010.] http://www.tc.gc.ca/eng/road-menu.htm.

61. **Natural Resources Canada.** National Private Vehicle Use Survey - October 1994 - September 1996. *Natural Resources Canada.* [Online] 04 20, 2009. [Cited: 07 16, 2010.] http://oee.nrcan.gc.ca/publications/infosource/pub/energy_use/NAPVUS/NAPVUSch4.cfm?attr=8.

62. **Statistics Canada.** 2006 Census of Canada: Topic based tabulations. *Statistics Canada.* [Online] 01 06, 2010. [Cited: 01 25, 2010.] http://www12.statcan.ca/census-recensement/2006/dp-pd/tbt/Rp-eng.cfm?TABID=1&LANG=E&APATH=3&DETAIL=0&DIM=0&FL=A&FREE=0&GC=0&GK=0&GRP=1&PID=90657&PRID=0&PTYPE=88971,97154&S=0&SHOWALL=0&SUB=763&Temporal=2006&THEME=76&VID=0&VNAMEE=&VNAMEF=.

63. **Statistics Canada.** 2006 Census of Canada: Topic-based tabulations. *Statistics Canada.* [Online] 01 06, 2010. [Cited: 01 25, 2010.] http://www12.statcan.ca/census-recensement/2006/dp-pd/tbt/Rp-eng.cfm?TABID=1&LANG=E&APATH=3&DETAIL=0&DIM=0&FL=A&FREE=0&GC=0&GK=0&GRP=1&PID=90655&PRID=0&PTYPE=88971,97154&S=0&SHOWALL=0&SUB=762&Temporal=2006&THEME=76&VID=0&VNAMEE=&VNAMEF=.

64. **Statistics Canada** Time taken to get to work and back "Table A1". *Statistics Canada.* [Online] n.d. [Cited: 07 20, 2010.] http://www.statcan.gc.ca/pub/89-622-x/2006001/t/4054735-eng.htm.

65. **Tesla Motors.** Charging solutions. *Tesla Motors.* [Online] 2010. [Cited: 10 27, 2010.] http://www.teslamotors.com/goelectric/charging.

66. **Natural Resources Canada.** Renewable Energy. *Natural Resources Canada.* [Online] 01 27, 2009. [Cited: 09 05, 2010.] http://nrcan.gc.ca/eneene/renren/aboaprren-eng.php.

67. **NRCan.** Residential Sector >Intro, Highlights. *Natural Resources Canada.* [Online] Natural Resources Canada, 06 22, 2010. [Cited: 09 05, 2010.] http://www.nrcan.gc.ca/eneene/effeff/resintro-eng.php.

68. **NRCan.** Transportation Sector > Intro, Highlights. *Natural Resources Canada.* [Online] 06 22, 2010. [Cited: 09 05, 2010.] http://www.nrcan.gc.ca/eneene/effeff/transintro-eng.php.

69. **Stephen Brown, David Pyke, and Paul Steenhof.** Electric vehicles: The role and importance of standards in an emerging market. 2010, pp. 3797-3806.