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Meeting residential space heating demand with wind-generated electricity

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Meeting residential space heating demand with wind-generated electricity

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Abstract

Worldwide, many electricity suppliers are faced with the challenge of trying to integrate intermittent renewables, notably wind, into their energy mix to meet the needs of those services that require a continuous supply of electricity. Solutions to intermittency include the use of rapid-response backup generation and chemical or mechanical storage of electricity. Meanwhile, in many jurisdictions with lengthy heating seasons, finding secure and preferably environmentally benign supplies of energy for space heating is also becoming a significant challenge because of volatile energy markets.

Most, if not all, electricity suppliers treat these twin challenges as separate issues: supply (integrating intermittent renewables) and demand (electric space heating). However, if space heating demand can be met from an intermittent supply of electricity, then both of these issues can be addressed simultaneously. One such approach is to use off-the-shelf electric thermal storage systems.

This paper examines the potential of this approach by applying the output from a 5.15 MW wind farm to the residential heating demands of detached households in the Canadian province of Prince Edward Island. The paper shows that for the heating season considered, up to 500 households could have over 95 percent of their space heating demand met from the wind farm in question. The benefits as well as the limitations of the approach are discussed in detail.

Keywords: Energy storage, energy services, electric space heating, energy security

1 Introduction

Concerns over energy security and climate change are forcing many electricity suppliers to review their portfolios (Grubb, Butler and Twomey 2006). Actions stemming from these reviews typically include measures to increase the use of electricity from renewables sources such as wind (Kydes 2007). However, integrating wind, an intermittent energy source, into an existing portfolio can present a number of additional challenges to the energy supplier ranging from grid stability to resource scheduling (E.ON 2005, Georgilakis 2008).

Intermittency can be addressed in a number of ways, one of the most common being the use of backup energy sources that can respond rapidly to an unexpected increase or decrease in the supply of electricity; such sources include hydroelectricity and gas turbines (Luickx, Delarue and D'haeseleer 2008). Another approach gaining interest, especially in jurisdictions with limited access to resources that can respond to rapid changes in wind supply, is to store any electricity produced, but not consumed, for subsequent use; for example, in batteries, pumped storage, or compressed air (Blarke and Lund 2008).

Energy suppliers are forced to go to these lengths when integrating significant quantities of wind into their portfolios because they must meet the demands of energy services that require continuous, uninterrupted supplies of electricity that are coincident with demand. A seldom discussed alternative is to match intermittent supplies of wind with energy services that are not unduly affected by rapid changes in electricity supply.

In many northern jurisdictions with lengthy heating seasons, modern life would not be possible without energy to meet the space heating needs in the residential, commercial, and institutional sectors. Depending upon the length of the heating season, space heating typically dwarfs the energy requirements of the other energy services used in these sectors. Fuel oil and natural gas are often the energy sources of choice because of their widespread availability and ease of use; however, growing concerns over energy security and greenhouse gas emissions are raising questions about the continued use of these energy sources for space heating. In some cases, consumers are often encouraged to heat with electricity as this is seen, or presented, as a clean and secure alternative, especially if the electricity is generated from domestic hydroelectric or nuclear sources.

Electric space heating is not without its challenges—baseboard (resistance) heaters and electric furnaces require access to continuous supplies of electricity. This can be problematic for electricity suppliers during the height of the heating season, when annual electricity demand is often at its greatest. In response, some electricity suppliers are encouraging their space heating consumers to switch to storage heaters that can be charged during off-peak periods (typically overnight) from base load generation and discharged throughout the day.

The fact that storage heaters need only be charged during specific hours of the day, albeit from a continuous supply of electricity, raises the question—could storage heaters be charged at anytime throughout the day from intermittent supplies of wind? If it were possible, consumers could have access to a secure and environmentally benign source of energy to meet their space heating needs.

This paper examines the technical potential of charging storage heaters at any time throughout the day from intermittent supplies of wind for meeting residential heating demand. Thermal storage systems designed to meet the average space heating requirements for single-detached residential homes in the Canadian province of Prince Edward Island are simulated using local temperature and wind farm production data. The simulation results show the benefits and limitations of using thermal storage units supplied by wind-generated electricity to meet residential heating demand.

2 Background

Prince Edward Island, Canada's smallest province, is situated in the Gulf of Saint Lawrence. It has limited energy resources, importing all of its refined petroleum products from Canadian refineries and most of its electricity. The majority of the refined petroleum products consumed in the province (like much of eastern Canada) come from crude oil from the North Sea, offshore Newfoundland, the Middle East, and Venezuela (Statistics Canada 2009). There is neither natural gas supply nor infrastructure on the island; most of the limited supply of natural gas in the region is exported to the United States. The high cost of electricity has made fuel oil the primary method of meeting heating needs for about 75 percent of residential structures in the province (NRCan 2008a).

Over the past forty years, successive federal and provincial governments have tried to reduce the province's reliance on imported energy (both oil and electricity). The advent of the modern wind turbine, coupled with the province's excellent wind resource, is seen as a means whereby the province could meet much of its own electrical needs as well as becoming an energy exporter to the lucrative New England renewable electricity market (PEI 2008).

2.1 Residential heating demand

In Prince Edward Island, as in many other northern jurisdictions, space heating is the dominant energy service in the residential sector with domestic hot water (DHW) a distant second. The demand by service for an average single-detached house in 2003 is shown in Table 1.

Table 1: Demand distribution by residential energy service (NRCan 2008b)

Service	Percent	kWh
Space Heating	68.4%	18,539
Water Heating	21.7%	5,879
Appliances	7.3%	1,969
Lighting	2.5%	673
Space Cooling	0.1%	16

For the purposes of this paper, hourly space heating demand is determined from the annual space heating demand (Table 1) and the hourly ambient temperature for Prince Edward Island's regional airport (Environment Canada 2008). Domestic hot water demand varies by hour and month; as this information is not available for Prince Edward Island, data from the Canadian province of Ontario is used instead (IESO 2009).

Figure 1 shows the monthly profile of space heating and domestic hot water demand (from hourly data) for an average single-detached home where demand is dominated by hot water supply during the summer months and space heating during the 2002-03 heating season (September through May). The data is centered on January, as this is the midpoint of the heating season.

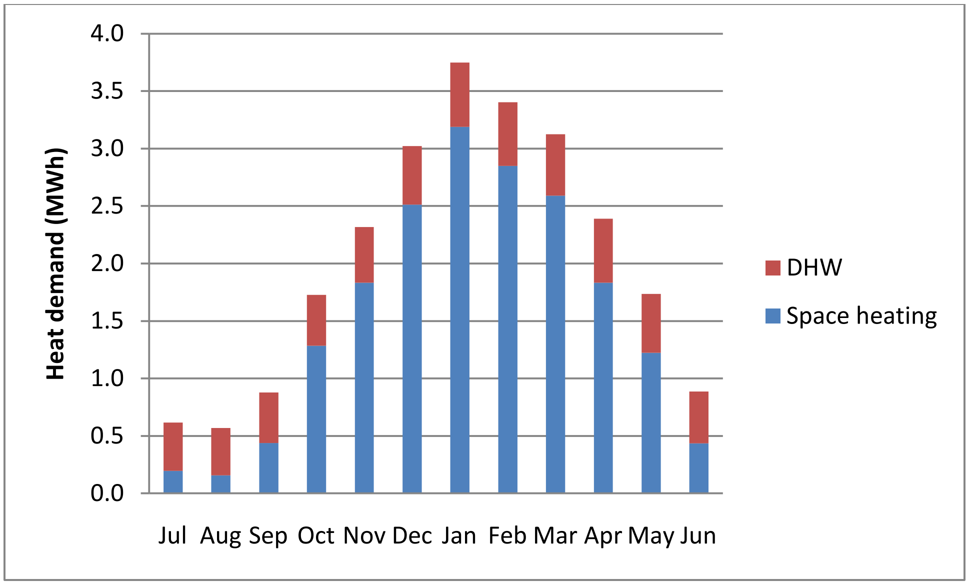

Figure 1: Monthly space heating and domestic hot water demand

2.2 Wind resource

Prince Edward Island has an excellent wind resource due to its geographic location in the Gulf of Saint Lawrence. This resource encouraged the provincial and federal governments to establish the Atlantic Wind Test Site at North Cape (AWTS 1999). By 2002, a wind farm with a capacity of about 5.15 MW had been established by the Prince Edward Island Energy Corporation (Energy, Environment and Forestry 2007). Maritime Electric, the province's electricity distributor, purchases the electricity and sells it to its customers. Between July 2002 and June 2003, the wind farm produced 17,453 MWh of electricity, giving it an annual capacity factor of 38.6 percent.

Production from the North Cape wind farm exceeded 1,500 MWh each month between October and March, with October and December reaching 2,002 MWh and 2,235 MWh, respectively. All other months, with the exception of July and May, had production values in excess of 1,000 MWh per month. Figure 2 shows the monthly totals (from hourly data) for 1 July 2002 to 30 June 2003.

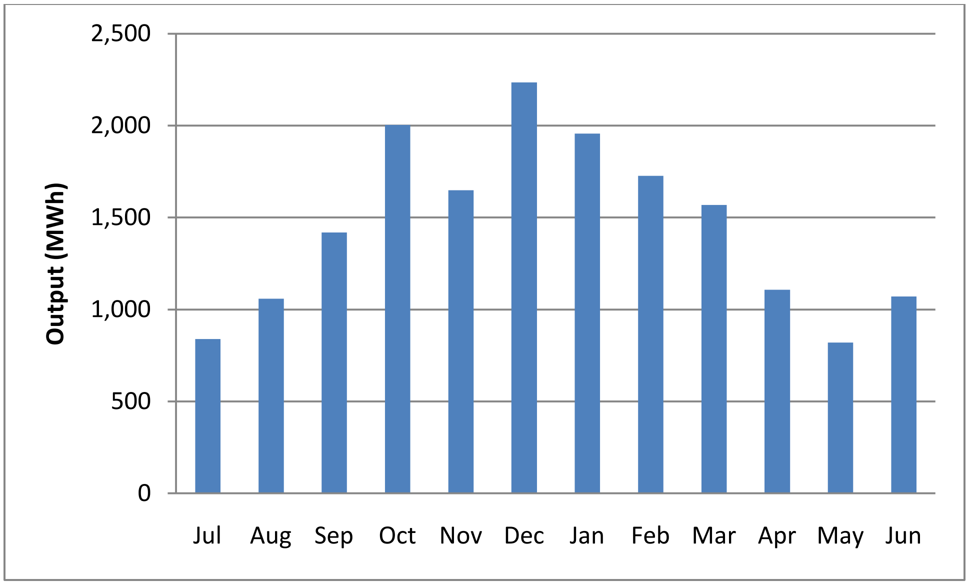

Figure 2: Monthly output from North Cape wind farm for 2002-03 heating season

3 Heating with wind

One of the principal arguments for generating electricity from the wind is that it does not emit greenhouse gases and is promoted as a "green" energy source. Another, potentially more compelling argument in a time of volatile energy prices, is that locally generated electricity from wind can be considered a secure source of energy.

Given the importance of space heating in many northern jurisdictions and its dominance in terms of overall residential energy consumption, space heating is one energy service that would benefit from an energy source that is both secure and environmentally benign. A jurisdiction with an adequate supply of wind and the necessary grid infrastructure could replace insecure energy supplies used for space heating with electricity from the wind.

The number of residential households that could have their space heating demand met from the wind over a year if no consideration is given to whether generation and demand is coincident (as is done by some electricity suppliers and media outlets) is:

$$\frac{\sum_{h=1}^{h=8760} wind_h}{\sum_{h=1}^{h=8760} demand_h} \quad \textbf{(1)}$$

where $wind$ is the hourly wind supply (kWh) and $demand$ is the hourly residential heating demand (kWh/household).

In the case of Prince Edward Island, applying the equation to the total wind output (17,453 MWh) and average household heating demand (18,539 kWh) suggests that 941 households could meet their heating demand from the wind farm. This is, of course, the ideal as it assumes that wind supply can meet demand even if the two are not time-coincident. Clearly, before wind can be used as a replacement energy source for space heating (or any other energy service for that matter), the energy service must be able to handle its intermittency.

4 Baseboard heating

Electric baseboard or resistance heaters are popular in some jurisdictions because they are inexpensive, easy to install, take up little living space, and are often presented as a clean way to heat a home (BC Hydro 2008). However, baseboard heaters require access to a continuous supply of electricity to meet demand that can occur at anytime throughout the day. The loss of electricity supply (for example, due to grid failure) means a loss of heat supply to the consumer.

During any hour throughout the heating season, the relationship between the wind supply and the baseboard demand falls into one of three categories:

- The wind supply equals the baseboard demand, meaning there is no surplus and all demand is met.
- The wind supply exceeds the baseboard demand and the heating demand is met; however, if the electricity that is surplus to demand cannot be stored, it cannot be used subsequently for heating.
- The wind supply is less than the baseboard demand, meaning that some or all of the demand must be met by another source, if it is available.

The percentage of baseboard demand that can be met by wind-generated electricity is governed by the amount of wind that is coincident with demand and the total baseboard heating demand from all households. During each hour of the year, the amount of energy available to meet the baseboard heating demand is the minimum of the hour's total demand and the available wind for that hour. Over the period of a year, the percentage of demand that can be met from the wind is expressed as follows:

$$\frac{\sum_{h=1}^{h=8760} \min(demand_h, wind_h)}{\sum_{h=1}^{h=8760} demand_h} \qquad \textbf{(2)}$$

Figure 3 shows the effect of increasing baseboard demand on the wind supply over the sample 12-month period.

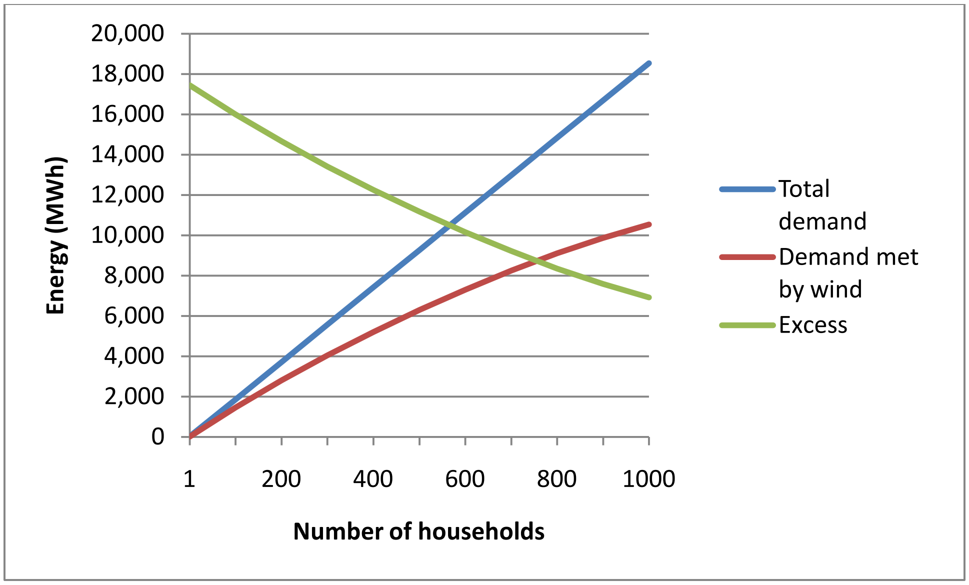

Figure 3: Allocation of wind electricity to households using baseboard heating

Demand increases linearly as a function of the number of households (the average annual space heating demand for each household is 18.54 MWh). If all 17,453 MWh of wind is made available throughout the year to a single household, only 84.7 percent of the household's heating demand is met, while over 99 percent (17,437 MWh) of the wind is surplus and available for other uses.

On the other hand, if 1,000 households are operating with baseboards, the annual household space heating demand reaches 18,539 MWh; although this exceeds the 17,453 MWh available from the wind, the wind can only supply 10,534 MWh (56.8 percent) of the demand because the wind is not always coincident with demand. The remaining 6,919 MWh (39.6 percent) of wind is surplus and cannot be used for heating the 1,000 households.

The amount of surplus wind not being used for heating will never reach zero, regardless of the household demand. The unused surplus occurs during those hours when the energy from the wind exceeds the heating demand. For example, during the year in question, there was no demand for wind energy 17 percent of the time (1,493 hours), amounting to 1,452 MWh or 8.3 percent of the total electricity produced.

5 Electric thermal-storage heating

During certain times of the year, wind-baseboard heating cannot meet the demand for heat because of the lack of supply from the wind. This can occur even when the annual electrical supply exceeds the annual heating demand. The problem can be solved using electricity from rapid-reaction backup sources (such as gas turbines or hydroelectric facilities) to bridge the gaps or by storing the electricity that is surplus to demand and applying it during periods of insufficient wind. Rather than requiring the electricity supplier to maintain potentially expensive backup, the storage and use of surplus electricity from the wind is now considered.

A storage medium can be designed to return electricity or heat. Given the losses associated with electricity storage and the fact that the electricity is to be used for heating purposes anyway, the paper considers the use of off-the-shelf thermal-storage medium only.

5.1 Electric thermal storage

Electric Thermal Storage, or ETS, is an alternative to existing baseboard electric heaters. In an ETS system, electricity is used to heat a storage medium (such as ceramic bricks) that subsequently releases the stored heat to the environment for space heating (typically a limited number of rooms or an entire house). With the addition of a heat exchanger, some ETS systems can also provide heat for domestic hot water (Steffes n.d.).

There are two types of ETS systems: room and central. A room-ETS system is sized to heat a limited number of rooms in a house, whereas a central-ETS system stores sufficient thermal energy to heat a house. Central-ETS systems are further subdivided into forced hot air and hydronic. Manufacturers specify an upper-limit on the amount of energy that can be stored in an ETS system; this dictates the system's maximum charging and, to a lesser extent, the discharging rates. Most ETS systems can run in a stand-alone fashion at a defined maximum output, typically 16 hours between charges.

One of the arguments for ETS is that it allows energy suppliers to shift loads from peak to off-peak periods, typically the eight hours between 23:00 and 07:00—the charged ETS systems can then discharge during the remainder of the day. ETS systems can charge and discharge simultaneously. Unlike other forms of electric heating, ETS has the advantage that its maximum demand is known by the energy supplier and the demand is met during specific times of the day.

Although ETS systems are typically charged by electricity suppliers during the overnight off-peak hours, the systems can be charged at any time, suggesting that they may lend themselves well to electricity generation from intermittent sources such as wind.

5.2 Wind-ETS heating

A wind-ETS heating system is a standard one that is charged when there is sufficient electricity available from the wind. Unlike wind-baseboard heating, during periods of insufficient wind the ETS system can draw on its store of heat to meet demand rather than relying on backup supply. The state of the ETS system (i.e., level of thermal energy in the system) at the start of each hour is determined by the previous hour's wind supply and household heating demand.

The hourly wind and demand data from Prince Edward Island allows a wind-ETS system to be simulated. The fundamental rule used in the simulation is that the ETS system should be kept at, or near, full capacity in order to bridge any periods of limited winds. The algorithm used in the simulations consists of three distinct steps (see Figure 4):

1. Attempt to meet the current hour's heating demand from any energy available from the wind.
2. If there is any energy from the wind remaining, attempt to apply it to the ETS system. The amount that can be applied is limited by the amount of wind, the state of the ETS system, and the system's maximum allowable hourly recharge rate:

   a) If charging will put the ETS system into a state less than its allowable maximum capacity, attempt to apply the electricity from the wind to the ETS system, up to the maximum allowable recharge.
   b) Otherwise, attempt to apply the electricity from the wind to the ETS system, up to its allowable maximum capacity.

3. If there is still remaining demand, attempt to use the ETS system to satisfy it. Ideally there is sufficient energy in the ETS system to satisfy the demand, otherwise as much demand as possible is met from the ETS system and some form of backup is required. Any remaining electricity from the wind is considered surplus for this hour and added to the overall surplus.

```
for hour = 1 to LastHourOfHeatingSeason do
    UnitWind = Wind [hour] $\div$ NumberOfUnits
    if UnitWind $\geq$ Demand[hour] then
        UnitWind = UnitWind - Demand[hour]
        Demand[hour] = 0
    else
        Demand[hour] = Demand[hour] - UnitWind
        UnitWind = 0
    end if
    if UnitWind $>$ 0 then
        if (ETS_State + UnitWind) $>$ ETS_maximum then
            UnitWind = (ETS_State + UnitWind) - ETS_maximum
            ETS_State = ETS_maximum
        else
            ETS_State = ETS_State + UnitWind
            UnitWind = 0
        end if
    end if
    if Demand[hour] $\neq$ 0 then
        if ETS_State $\geq$ Demand[hour] then
            ETS_State = ETS_State - Demand[hour]
            Demand[hour] = 0
        else
            Demand[hour] = Demand[hour] - ETS_State
            ETS_State = 0
        end if

        if Demand[hour] $\neq$ 0 then
            HoursWithoutHeat = HoursWithoutHeat + 1
            TotalWithoutHeat = TotalWithoutHeat + Demand[hour]
        end if
    end if
    ExcessWind = ExcessWind + UnitWind $\times$ NumberOfUnits
end do
```

Figure 4: Algorithm for ETS system heated by the wind.

The maximum storage capacities and the maximum allowable recharge of the ETS systems used in the simulations are shown in Table 2.

Table 2: ETS system characteristics (adapted from (Steffes n.d.))

Maximum ETS capacity (kWh)	120	180	240
Maximum allowable recharge (kW)	15.0	22.5	30.0

An ETS system that is not charged will self-discharge over a period of time (a fully charged 180 kWh ETS system takes about 10 days to self-discharge (Steffes n.d.)). Self-discharging is not considered in this paper.

5.3 Storage size

The availability of storage allows wind-ETS systems to operate when there is insufficient wind to meet demand. However, ETS systems are limited since prolonged periods during which the discharge rate exceeds the recharge rate will deplete the store, potentially leading the ETS system to become completely discharged.

When there is insufficient wind to meet demand, heat will be removed from the ETS system (discharging), at some point in the future when there is sufficient electricity from the wind to meet demand, heat will be added to the ETS system (charging). The amount of storage (in kWh) required by the ETS system to bridge the gap from the hour when an ETS's state begins to decrease to the hour it begins to increase must satisfy the following equation if the storage is not to be completely discharged:

$$state_{DecreaseHour} > \left(\sum_{h=DecreaseHour}^{h<IncreaseHour} discharge_h - charge_h\right) \qquad \textbf{(3)}$$

where $DecreaseHour$ is the hour at which the state of the ETS system begins to decline relative to the previous hour and $IncreaseHour$ is the hour when the ETS system state begins to increase, relative to the previous hour. $State$, $discharge$, and $charge$ are the ETS system state, the required heating discharge for the hour, and the charge supplied by the wind for the hour, respectively (all in kWh).

An example of how the state of an ETS system can change due to the availability of wind is shown in Figure 5, where the hourly simulation results for three different sizes of ETS systems (120, 180, and 240 kWh) meeting the same demand over four days (11 December to 14 December) are presented. In this simulation, a total of 500 ETS systems are supplied with electricity from the wind farm.

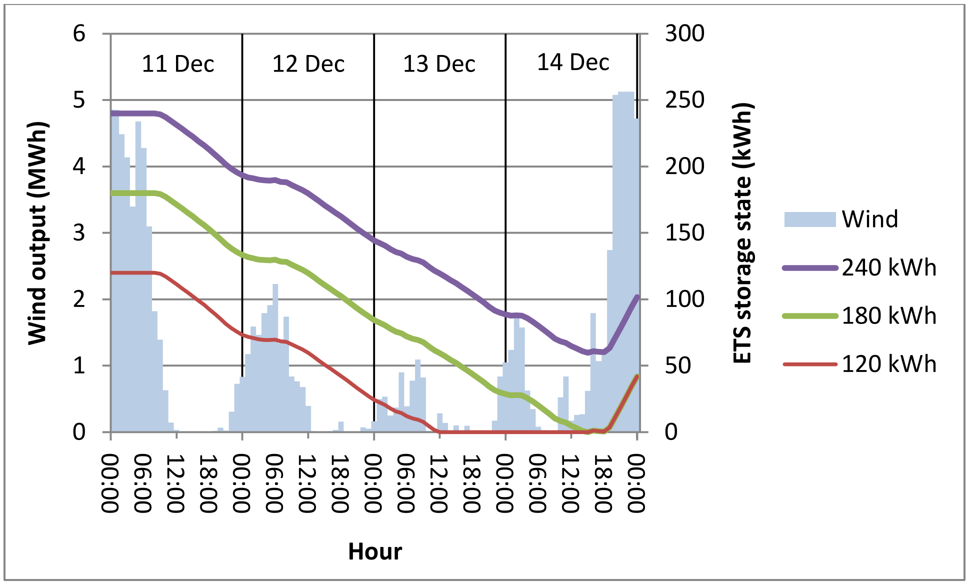

Figure 5: Changes in ETS state during four days of limited wind supply

At 09:00 on 11 December, the three sample ETS systems were fully charged. Between 09:00 and 10:00, the heating demand was 1.74 MWh, while the wind supply was 1.39 MWh, meaning that there was insufficient electricity from the wind to restore the energy used for heating during that hour. Electricity output from the wind farm continued to fall and by 13:00, output from the wind farm reached zero. Electricity production was limited and sporadic until 16:00 on 14 December, at which point there was sufficient production to resume adding heat to the ETS systems.

The total heating demand for all 500 ETS systems during the 79 hours in question was 127.4 MWh, while the wind produced 37.4 MWh of electricity. The difference between the supply and demand for the 79 hours in each of the sample ETS systems was 180.3 kWh, meaning that neither the 120 kWh nor the 180 kWh ETS systems could meet all of the heating demand. During part of this period, both the 120 kWh and the 180 kWh ETS systems became fully depleted, meaning that for some of the time heating backup was required (see Table 3).

Table 3: Heating sources when ETS fully depleted

ETS size	Hours ETS empty	Heating demand (kWh)	Wind supply (kWh)	Backup required (kWh)
120	34	84.0	22.0	61.9
180	1	2.5	1.2	1.2

5.4 Increasing the number of ETS systems

As the number of ETS systems increases, more of the electricity from the wind is used for heating and the amount of surplus electricity decreases; however, this can reduce the amount of electricity available per system for recharging or meeting demand. Although increasing the storage size can reduce the likelihood of the complete discharge of an ETS system, the addition of more ETS systems can increase the time required for a complete recharge. The lower the state of charge of an ETS system, the greater the probability of a complete discharge should the wind supply decline.

These effects are illustrated in Figure 6, where 500, 600, and 700 ETS systems of 240 kWh capacity are simulated over 10 days (19 January to 28 January). The state of the ETS systems is shown: as the number of ETS systems increases, the available energy is shared by more systems, leading to slower replenishments and, because of the resulting lower storage states, the greater the likelihood of depleting the ETS system completely.

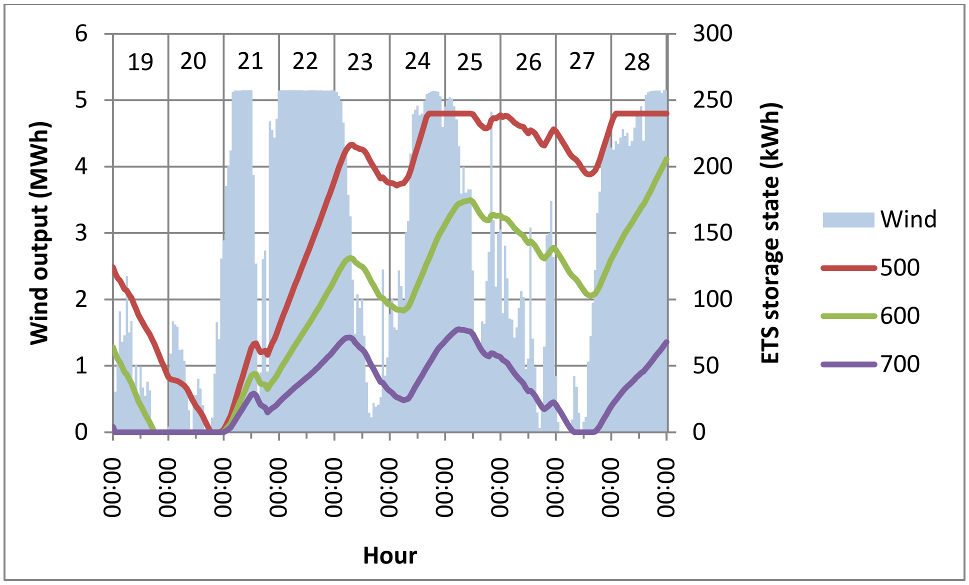

Figure 6: Effect of increasing the number of ETS systems

5.5 Meeting demand from the wind

The percentage of the space heating demand that can be met by a wind-ETS system is obtained from the following equation:

$$\frac{\sum_{h=1}^{h=8760} \min(demand_h, ETS_h + wind_h)}{\sum_{h=1}^{h=8760} demand_h} \quad \textbf{(4)}$$

where $demand$, ETS, and $wind$ are the hourly household demand, the household's ETS system state, and the fraction of the electricity from the wind available to the household, respectively (in kWh). The amount of energy available to meet the household heating demand for each hour of the year is the minimum of the demand and the energy from the sum of the ETS system states and the wind. If for each hour of the year, the demand is less than the combined availability of the ETS and wind for that hour, the annual heating demand is met entirely from the wind; however, should demand exceed the supply of energy from the ETS system and wind for one or more hours throughout the year, wind will meet less than 100 percent of the total demand.

The effects of varying the number of ETS systems and their capacities over the simulation period are shown in Figure 7 (baseboard is included for comparison purposes). More than 95 percent of the space heating demand can be met from the wind if there are less than 500 systems, regardless of the ETS system capacity. By increasing the capacity, more demand can be met from the wind; for example, over 99 percent for 500 ETS systems with capacities of 240 kWh.

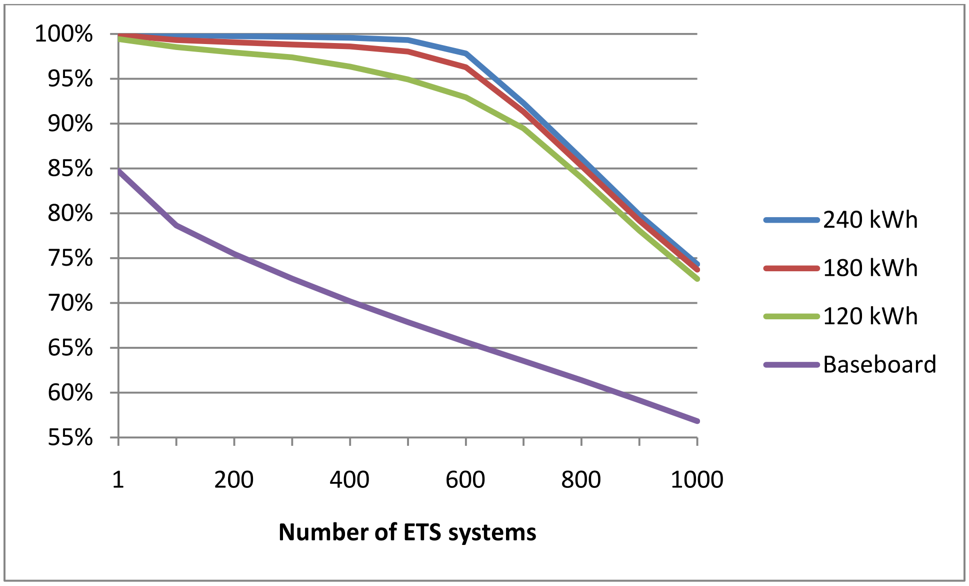

Figure 7: Percentage of heat from wind for different ETS capacities and number of systems

As the number of 180 kWh and 240 kWh ETS systems increase beyond 500, the percentage of heat supplied by the wind begins to decrease significantly. Table 4 shows the effect of increasing the number of 240 kWh ETS systems from 500 to 700, resulting in a tenfold increase in the number of hours the ETS systems are fully discharged and the amount of backup required. Increasing the number of systems increases the number and duration of heating events (i.e., periods without heat from the ETS).

Table 4: Effect of increasing the number of ETS systems

Number of ETS systems	Heating from wind	ETS empty (hours)	Backup supply (kWh)	Total heating events	Minimum duration (hours)	Maximum duration (hours)	Average duration (hours)
500	99.5%	55	126	6	2.0	17.0	9.2
600	98.3%	162	409	11	1.0	29.0	14.7
700	94.1%	537	1,430	32	1.0	54.0	16.8

Regardless of their capacity, increasing the number of ETS systems beyond 800 results in the convergence of the percentage of heat that can be supplied by the wind. At this point, the demand for heat is so great during parts of the heating season that the ETS systems never get the opportunity to obtain more than a partial recharge.

Finally, increasing the number of ETS systems and their capacities results in a decrease in the amount of surplus electricity (see Figure 8).

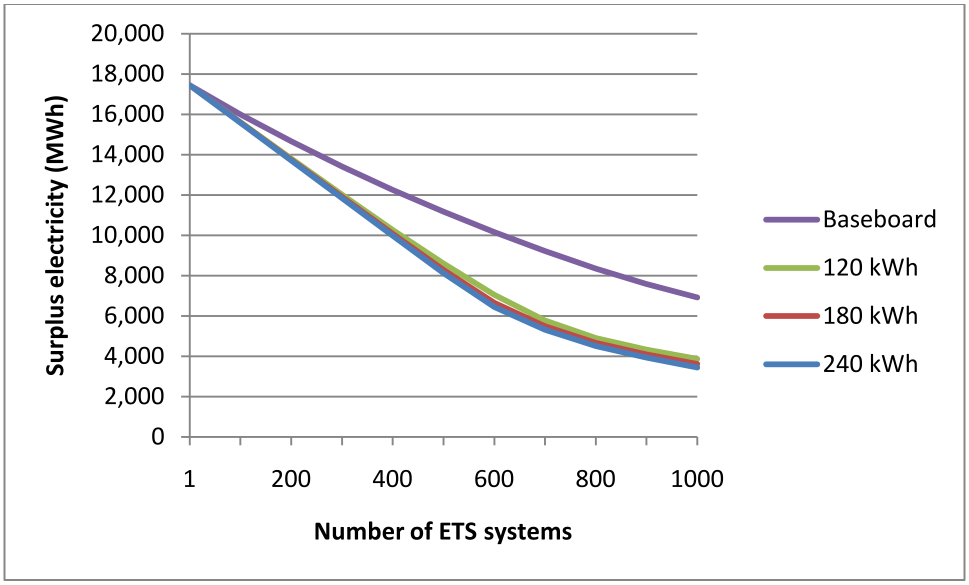

Figure 8: Decline in surplus electricity

5.6 Space heating and domestic hot water

ETS units that can be used for both space heating and domestic hot water supply allow more of the electricity from the wind to be used for heating purposes, adding an extra 5.8 MWh of heating demand to the average residential load. This increases demand throughout the heating season as well as extending demand into the summer months. This means that, when compared to space heating demand alone, there is less electricity surplus to demand as the number of units increase; Figure 9 shows this for an increasing number of 240 kWh ETS systems.

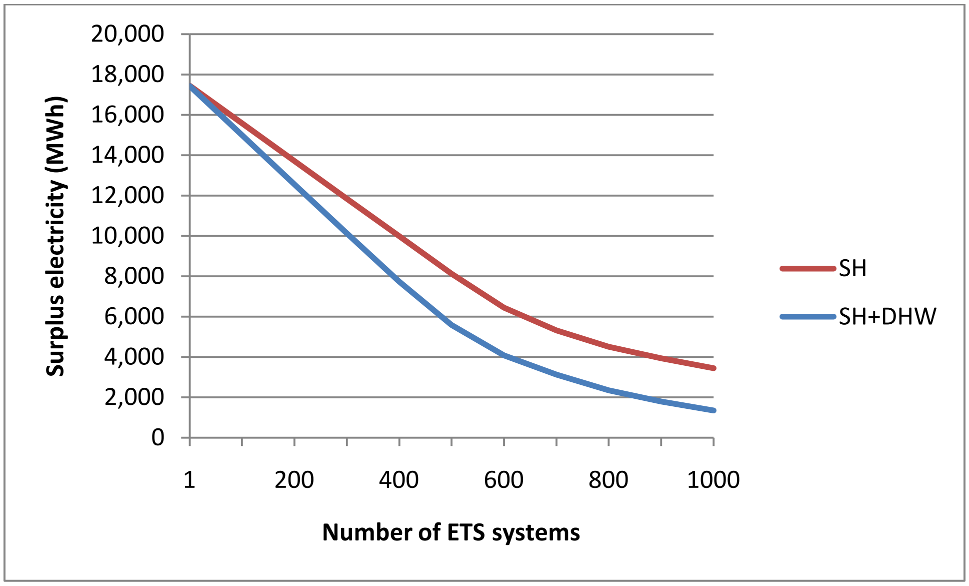

Figure 9: Effect on surplus electricity when domestic hot water is included

Although adding domestic hot water means that there is less surplus electricity, the extra demand reduces the percentage of heat available for the overall heating load (see Figure 10).

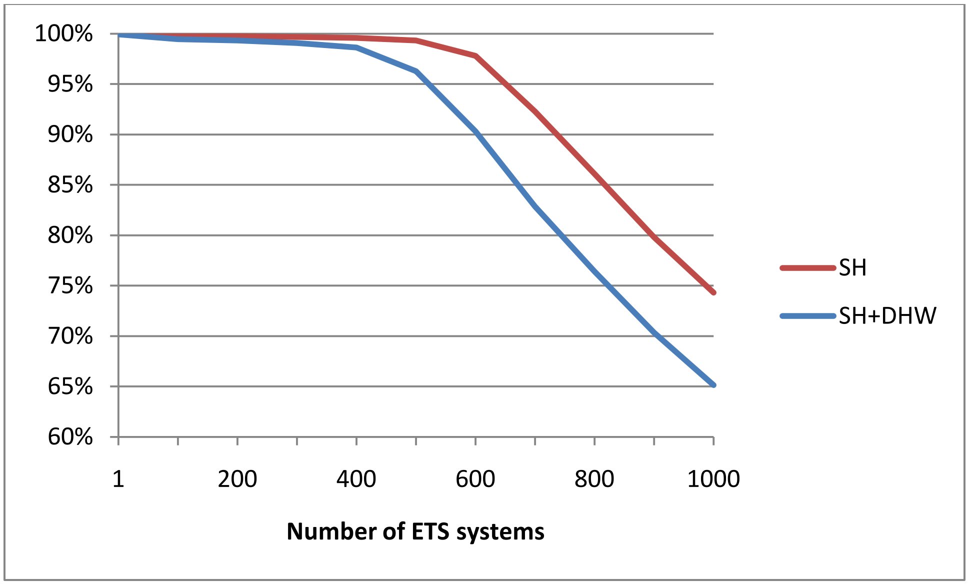

Figure 10: Percent of wind electricity available for heating

6 Discussion

The simulations in this paper show that the combination of thermal storage heaters and wind-generated electricity can be employed as a means to meet residential space heating demand. Since surpluses of electricity and heating shortages can still occur, the twin challenges of addressing wind's intermittency and achieving heating security may have been diminished, but still remain. The dichotomy lies in the amount of storage:

- The thermal storage systems used in the simulations cannot "absorb" electricity indefinitely; surplus production will always occur, even when using 240 kWh systems. This surplus is effectively a form of intermittency as it can occur at anytime without prior warning to the electricity supplier.
- The limited capacity of the thermal storage systems means that during prolonged periods of low temperatures and insufficient wind the ETS systems may become completely discharged, requiring the household to find other sources of energy for heating.

Decreasing the number of ETS systems improves heating security but creates greater surpluses, while increasing the number of ETS systems reduces the size of the surplus at the expense of heating security.

The application of wind and temperature forecasting and knowledge of the ETS state offers a partial solution, as it may allow charging to be delayed and the electricity applied to other services. Alternatively, the electricity supplier may be able to offset complete discharges by supplementing the wind during off-peak hours.

Meeting residential space heating requirements can be achieved using electricity supplied by the wind and thermal storage. Although in most instances, some form of backup is probably required, wind-heating can reduce the jurisdiction's reliance on insecure sources of energy. Another benefit of wind-heating is that it is a carbon-free source of energy.

Meeting residential space heating requirements can be achieved using electricity supplied by the wind and thermal storage. Although in most instances, some form of backup is probably required, wind-heating can reduce the jurisdiction's reliance on insecure sources of energy. Another benefit of wind-heating is that it is an emissions-free source of energy, meaning that the amount of, for example, carbon dioxide emitted for space heating, should decline.

In Prince Edward Island, the average space heating related emissions from a single detached house is 4.37 tonnes of CO_2e [17]. Figure 11 shows the CO_2e emissions associated with houses using an existing fuel-oil furnace and those using a 180 kWh ETS system supplied with electricity from the wind. The CO_2e emissions from houses with thermal storage are assumed to come from a fuel-oil furnace operating as the backup system. The actual reduction benefits would ultimately depend upon the energy sources used to back up the ETS systems.

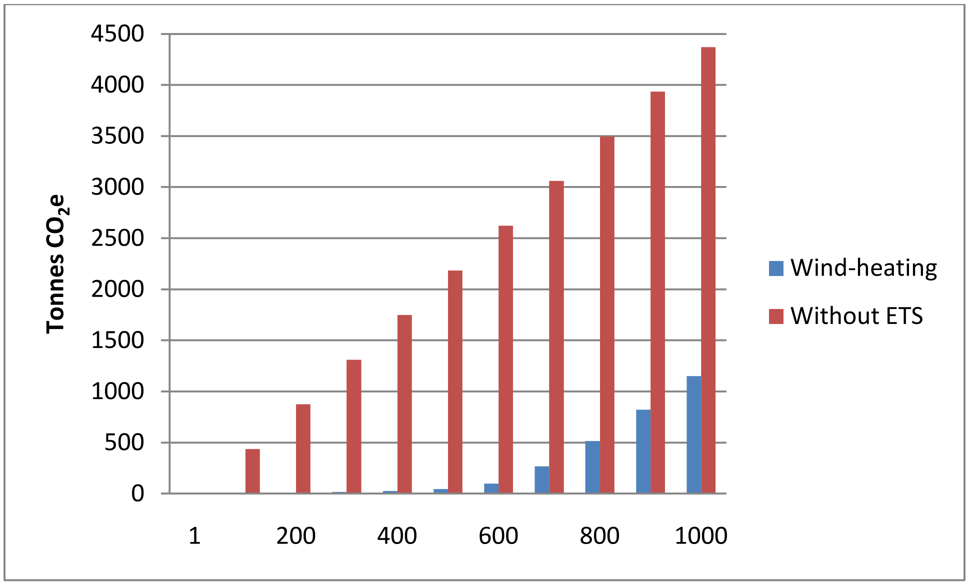

Figure 11: CO_2e emissions for detached households with and without wind-ETS

7 Concluding remarks

Energy security and greenhouse gas emissions are two dominant energy issues facing many jurisdictions. Successfully addressing these issues will mean finding supplies of energy that are both secure and environmentally benign. Wind-generated electricity is often presented as an energy source that meets these criteria.

Traditionally, electricity systems have been designed to offer a continuous supply of electricity to meet the needs of all energy services (whether a continuous supply is required or not). Wind, being intermittent, needs some form of backup or storage if significant quantities of wind are to be incorporated into an electricity supplier's portfolio. Alternatively, energy services that can operate without a continuous supply of electricity may be ideal candidates for obtaining electricity from the wind.

One such energy service is space heating with electric thermal storage. An ETS system that allows charging at anytime means that, ideally, the electricity supplier has a load that is ready to accept electricity from the wind whenever it is available.

The Prince Edward Island wind farm and residential heating demand simulations demonstrate the potential of this approach—up to 500 households could have over 95 percent of their space heating demands met from the wind. This also reduces the amount of intermittent electricity with which the electricity supplier must deal. It was shown that increasing the number of households and the capacity of their ETS systems does reduce the amount of surplus electricity but also reduces the amount of space heating met by the wind.

The principal factor that limits the amount of space heating that can be met from the wind is the capacity of the ETS system and its ability to bridge the periods of insufficient wind-generated electricity. This can be addressed in a number of ways: the electricity supplier can offer backup supplies of electricity, the household can have other energy sources for space heating, or the ETS system can be equipped with a larger storage capacity. Increasing the storage capacity will also lead to a reduction in the amount of surplus electricity with which the electricity supplier must deal.

This paper has shown that although there can be periods of surplus and supply shortfalls, using wind to meet residential space heating demand can reduce the reliance on energy supplies that are potentially insecure and environmentally damaging, such as fuel oil and natural gas. We are presently examining other methods of improving the ways in which wind can be used for heating, including other forms of backup, seasonal storage, and centralized control of ETS systems.

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