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Ground Source Heat Pump Systems in Canada

Economics and GHG Reduction Potential

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RESOURCES FOR THE FUTURE

Ground Source Heat Pump Systems in Canada: Economics and GHG Reduction Potential

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Abstract

Climate stabilization requires greenhouse gas reductions (GHG) in excess of 60 percent. Ground source heat pumps (GSHPs) hold the promise of meeting heating and cooling loads much more efficiently than conventional technologies. The economic viability of their widespread adoption depends on the costs of energy. Their impact on GHG reduction depends on fuel choices both in electricity generation and on customers' premises. In this paper, we provide a systematic assessment of the GHG reduction potential across Canada of GSHPs and the economic cost of achieving this reduction. Using province-level data on household fuel choices and energy use, we find that GSHP systems offer significant GHG reductions, as well as savings in operation and maintenance costs. However, high capital costs continue to limit market diffusion. We conclude with a review of the geological suitability of the five largest urban centers in Canada for GSHP installation. This analysis shows GSHPs to hold significant potential for substantial GHG reductions in Canada at a cost savings relative to conventional alternatives, with time horizons as short as seven years.

Key Words: conservation, GHG mitigation, residential energy

JEL Classification Numbers: Q40, Q41, Q52

Contents

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Introduction

Climate stabilization requires greenhouse gas reductions (GHG) in excess of 60 percent. Ground source heat pumps (GSHPs) hold the promise of meeting heating and cooling loads much more efficiently than conventional technologies. The economic viability of their widespread adoption, however, depends on the costs of energy, and their impact on GHG reduction depends on fuel choices both in electricity generation and on customers' premises. In this paper, we provide a systematic assessment of the GHG reduction potential across Canada of GSHPs and the economic cost of achieving this reduction.

Despite the promise of significant GHG reductions and energy cost savings to consumers, GSHP systems have had limited market diffusion. There are three reasons for this: 1) their initial capital costs are significant; 2) system designs have not been standardized and actual performance of systems has sometimes fallen short of its promise; and 3) significant economies of scale and scope are rarely exploited.

The goal of this study is to inform the decisions of developers and homeowners about the desirability of GSHP systems for energy services in colder climates. The key criteria for evaluation of desirability used here are lifetime costs and GHG reduction. These vary by location according to the costs of electricity, gas, and oil, the electricity generation mix, the norms in fuel choice used to provide heat, and local geology. In this study we examine the conditions in each province and territory to provide locally relevant insights into the suitability of GSHP and its potential to reduce GHG emissions in the long run.

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Methodology

Fuel Choice

The key elements of this study are energy-use patterns, fuel choice, the electricity generation mix, and fuel and electricity costs. Data on household energy use for 2004 are available through the Comprehensive Energy Use Database, Natural Resources Canada (NRCan). We used the available regional data on space and water heating to explore choices for the typical 140m^2 (1,500 sq ft) house in different Canadian provinces.[1]

The demand for heating and cooling is met using a variety of technologies, some of which are more efficient in converting energy inputs into energy services. Radiant electric systems have end-use efficiencies of almost 100 percent, while gas and oil-fired systems rarely achieve 90 percent efficiency and vary in their efficiency depending on the vintage and design of furnaces being used. Given regional differences in housing stocks, the average efficiency of the current furnace stock vary from region to region, ranging from 63 percent to 74 percent for oil and 69 percent to 77 percent for natural gas. Conventional cooling systems achieve efficiencies equivalent to a coefficient of performance (COP) of 2.7 (NRCan 2005a).

Table 1 provides a summary of fuel choices by region; in each region the most common fuel choice is highlighted. In contrast to conventional technologies, heat pumps operate at a COP of between 3 and 5, which translates into efficiencies of 300 percent to 500 percent.[2] This efficiency variation occurs due to a number of variables, including soil conditions, hydraulic conductivity, and whether systems are properly sized and installed. Mid-range efficiencies of $COP_{heating}$ of 4 and $COP_{cooling}$ equivalent to 5 are used for this study (Federal Energy Management Program 2001).

[1] The average size of homes in Canada increased from 116m^2 for homes built before 1960 to 142m^2 for those built after 2000 (NRCan 2006)

[2] Coefficient of performance is the ratio of useful energy out to electric energy input to the heat pump; the COP is a function of local conditions and type of GSHP system. Efficiencies of more than 500 percent are attainable with new technologies under ideal conditions.

Table 1. Share of Energy Sources for Space and Water Heating, by Region

	Space Heating (%)			Water Heating (%)		
Region	Natural Gas	Electricity	Heating Oil	Natural Gas	Electricity	Heating Oil
Newfoundland	0	35	38	0	88	12
Prince Edward Island	0	2	80	0	33	65
Nova Scotia	0	13	68	0	61	38
New Brunswick	3	36	29	0	61	38
Québec	10	39	21	4	92	0
Ontario	74	11	8	64	33	2
Manitoba	64	24	1	53	46	0
Saskatchewan	86	5	1	78	21	1
Alberta	95	3	0	90	9	1
British Columbia	69	19	1	52	47	1
Territories	8	3	65	0	76	24

The market share of space heating systems has been evolving over the past decade (Figure 1). The most prominent trend has been the growing share of high- and medium-efficiency gas-fired systems. Heat pumps have also been gaining ground, but the stock of baseboard electric heat has remained relatively constant. However, these trends at the national level hide significant regional variations in heating system choice. Table 2 presents the average annual installations of new systems by province. The most common fuel choices over the last five years are medium- and high-efficiency natural gas and medium-efficiency heating oil furnaces (there has been no significant adoption of high-efficiency oil furnaces).

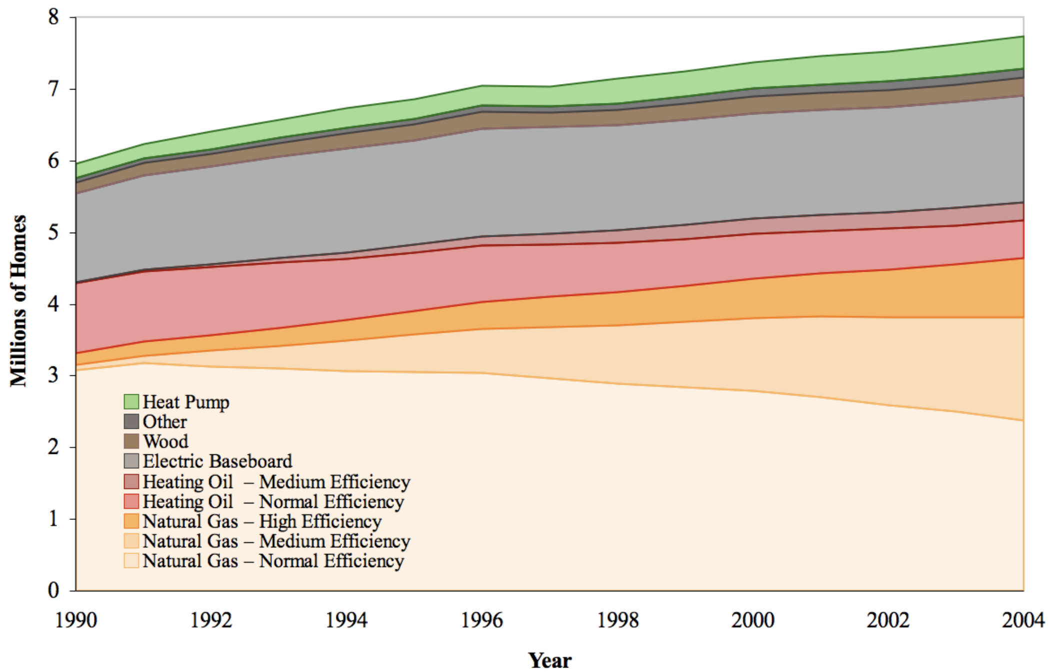


Figure 1. Market Share of Space Heating Systems in Canada, 1990–2004

Table 2. Net Annual Marginal Growth of Space Heating System Stock for Detached Homes, by Region

Region	Natural Gas	Electric Baseboard	Heating Oil	Heat Pump[3]
Newfoundland	n/a	1,700	300	100
Prince Edward Island	n/a	<100	300	< 100
Nova Scotia	n/a	500	1,200	500
New Brunswick	n/a	2,100	1,000	300
Québec	2,100	5,300	3,500	5,800
Ontario	76,000	900	4,100	10,000
Manitoba	6,300	700	700	400
Saskatchewan	7,200	<100	100	300
Alberta	30,000	600	400	800
British Columbia	15,000	800	800	1,400
Territories	100	< 100	200	n/a

Note: n/a areas represent regions where a fuel is not used.

[3] The vast majority of these units are air-exchange heat pumps. They offer efficiency gains over conventional systems but operate at high efficiencies over a narrower temperature range, and have a service life that is significantly shorter than GSHP systems.

Energy Demand

We use a standard energy demand model for a 140 m^2 (1500 sq ft) home to calculate heating and cooling loads for each region (NRCan 2005a). In cold climates such as in Canada, GSHPs represent a viable alternative to conventional space heating and cooling systems due to their higher operating efficiency, especially during the heating season (Healy and Ugursal 1997). Since the heating load varies on a yearly basis, the energy requirements are adjusted for annual temperature fluctuations in each region using the NRCan Heating Degree Day and Cooing Degree Day Index.[4]

Space and water heating needs and cooling loads are summarized in Table 3.[5] Discrepancies between energy services used and the actual heating load stem from the fact that heating technologies achieve differing efficiencies (i.e., the average natural gas furnace operates at ~70 percent efficiency and therefore uses more energy than the actual heating load). Our goal is to cost out GSHP systems on the basis of energy services delivered; we include air conditioning demands in our calculations since ground source heat operates as a heating system in the winter and as an air conditioning system in the summer.

Table 3. Energy Services in an Average Home, by Region

	Space Heating		Water Heating		Air Conditioning	
Region	Energy Used (GJ)	Heating Load (GJ)	Energy Used (GJ)	Heating Load (GJ)	Typical A/C (kWh)	GSHP A/C (kWh)
Newfoundland	75	50	25	20	85	45
Prince Edward Island	65	40	25	20	80	45
Nova Scotia	60	40	25	20	150	80
New Brunswick	80	60	30	25	170	90
Québec	85	60	30	30	750	400
Ontario	75	55	30	25	980	530
Manitoba	70	55	35	30	1,090	585
Saskatchewan	90	60	35	30	570	305
Alberta	115	80	55	40	220	115
British Columbia	50	40	30	20	305	165
Territories	65	40	20	20	0	0

[4] The Heating Degree Day Index is a measure of how relatively cold (or hot) a year was compared with an average year. When the HDD is above (below) 1, the observed temperature is colder (warmer) than normal. A Cooling Degree Day Index below (above) 1 indicates the observed temperature was colder than the average (NRCan, 2006).

[5] Climate change and high glass areas combined with solar gain are leading to increasing demand for cooling in new built structures across Canada.

Informing consumers about the economics of GSHP compared to conventional energy systems requires estimation of the total cost of delivering energy services. These include standing charges, delivery costs, fuel charges and taxes, as well as equipment purchase and maintenance costs. For the energy cost calculations we include utility fixed and variable rates, connection charges, local levies, discounts (if applicable) and taxes. Pricing structure data are easily obtainable from online customer resources of each utility. The system costs for conventional heating and cooling systems are well established, as is their life expectancy and annual maintenance costs. Even though the costs of installing GSHPs are highly variable and site specific (i.e., the load and local geology determines the cost of drilling), their reliability and life expectancy are well known. Ground source heat has a 25-year life cycle and is virtually maintenance free, while ground loop piping should last more than 50 years (Geothermal Heat Consortium 2006).

GHG Intensities

Detailed GHG intensities of electricity generation are provided in Canada's Greenhouse Gas Inventory, and the latest available data are from 2004[6]. In order to accurately assess the emissions attributable to heat pump operation in each region, we include emissions embodied in electricity imports in electricity intensities (Table 4). Electricity trade data are obtained from the National Energy Board (2005).

Continued discussions on how to best account for CO_2 embodied in energy trade demonstrate the lack of consistency in GHG accounting principles; this affirms the need for establishing standards for CO_2 accounting at both the international and inter-provincial levels (Munksgaard and Pedersen 2001). In order to approach consensus on GHG accounting, we explore the implications of two additional methods of GHGs embodied in imported electricity (these are outlined in the sensitivity analysis detailed in Table A3 in Appendix A).

[6] For some provinces, access to electricity-related emissions was restricted, as they were made confidential after the year 2000. In these cases, 2000 GHG intensities were used.

Table 4. Carbon Intensities Obtained from Local Electricity Generation Alone and with Inclusion of Embodied Emissions in Electricity Imports, by Region

Emission Intensity	Generation Only (tCO_{2eq}/GWh)	Generation and Imports (tCO_{2eq}/GWh)
Newfoundland	21	21
Prince Edward Island	1,120	464
Nova Scotia	759	751
New Brunswick	433	435
Québec	8	29
Ontario	222	229
Manitoba	31	100
Saskatchewan	840	833
Alberta	861	844
British Columbia	24	84
Territories	249	249

Operational Savings

We determine heating and cooling cost baselines of homes using three conventional fuels (natural gas, electricity, and heating oil) for space and water heating and electricity for air conditioning. Since GSHP systems have a higher upfront cost than conventional heating and cooling systems, we compare these costs to the cumulative savings achieved through the annual operational savings of a GSHP system. GSHP operating savings are discounted at a rate of 7.5 percent (±2.5 percent) to obtain a breakeven threshold for three payback periods (5, 10, and 20 years). Since the variability of average costs is substantial, this paper aims to provide financial guidelines that help determine whether a home's conditions are suitable for GSHP, as is further described below.

Results

GHG Reductions

The GHG emissions reductions achieved by a GSHP system depend on the carbon intensity of the fossil fuel being substituted, as well as the carbon intensity of the electricity used to drive the heat pump. The emissions reductions for an average Canadian home (area ~140 m^2) are illustrated in Figure 2, supplemented by Table 5. A COP of 4 was used in conjunction with emission intensities that reflect electricity both electricity generation and imports.[7] Provincial-level data illustrate the dependence of GSHP systems' environmental effectiveness on the carbon content of electricity.

In all provinces where GSHP substitutes natural gas, we observe reductions in emissions; these range from 3.9t in British Columbia on the West Coast to 5t in Newfoundland on the East Coast. In Alberta and Saskatchewan, where the electricity is generated mostly from sub-bituminous coal, the carbon intensity of the electricity is high and GSHP systems only provide 1.6t and 1.3t of CO_2 savings, respectively.

When GSHPs are compared to electric heating, the most significant GHG reductions are also evident in regions dependent on coal-based electricity generation (Figure 2b). Provinces with low electricity intensities (Newfoundland and Québec) only achieve less than 1t reductions when switching form electricity to GSHP due to the preexisting low-carbon footprint. Conversely, Alberta and Saskatchewan demonstrate dramatic reduction potential of 22.3t and 16.1t, respectively.

A transition from heating oil to GSHP would entail annual GHG reductions exceeding 5t per household in all provinces, with the exception of Prince Edward Island and Nova Scotia (where reductions are 4.7t and 3.7t, respectively). Switching out of oil-fired systems is highly advisable throughout Canada due to the cost savings attainable by the average home.

[7] Some fuels are not available in certain regions for heating (i.e., natural gas is not used in the territories, Newfoundland, Prince Edward Island, and Nova Scotia for heating, while heating oil is not used in the Western provinces.)

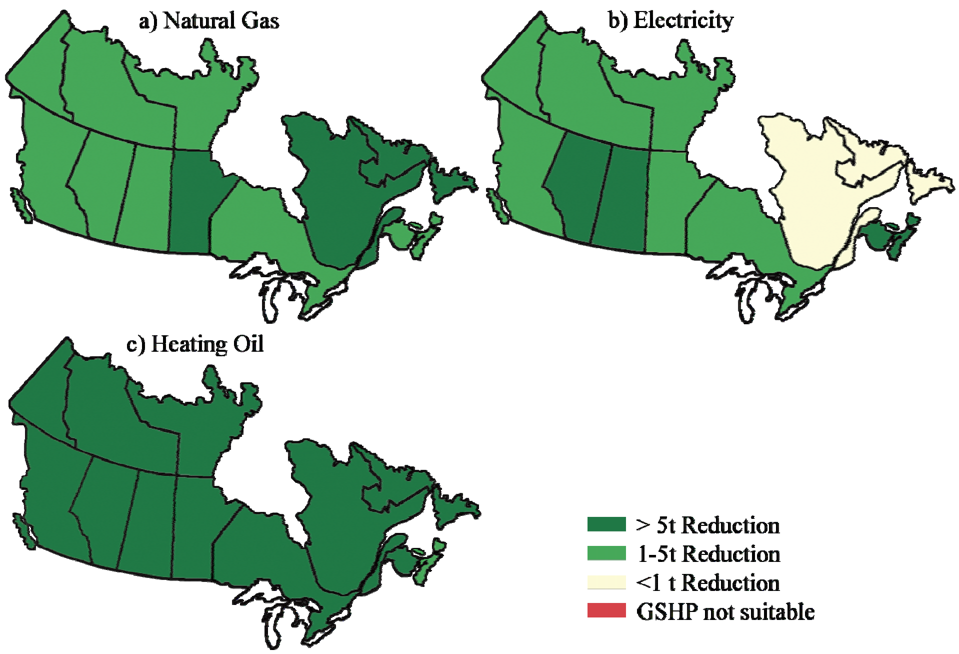


Figure 2. Annual Reduction in Tons of CO_{2eq} through Use of GSHP Systems, by Province

Table 5. Tons of CO_2 Averted by Use of GSHP, by Region (140 m^2 home, COP 4)

	GSHP Emissions Reductions Relative to		
	Natural Gas (t)	Electricity (t)	Heating Oil (t)
Newfoundland	5.0	0.3	8.1
Prince Edward Island	2.3	6.0	4.7
Nova Scotia	1.1	9.7	3.7
New Brunswick	2.9	7.6	6.5
Québec	6.1	0.6	9.8
Ontario	4.3	4.0	7.4
Manitoba	5.1	1.8	8.1
Saskatchewan	1.3	16.1	5.1
Alberta	1.6	22.3	5.2
British Columbia	3.9	1.1	6.4
Territories	2.8	3.1	5.5

Table 6 illustrates the total reduction potential based on the average-sized home; the most crucial heating options to be targeted for fuel switching in each province are depicted in the shaded cells. Policies targeting heating oil customers will have the most effect in the maritime provinces, whereas in central and western Canada, the natural gas consumer base holds the most significant GHG-reduction potential.

Table 6. Annual GHG Savings Potential for GSHP, by Region (140 m^2 home, COP 4)

	Total Attainable GSHP Emissions Reductions by Switching to GSHP from		
	Natural Gas (kt)	Electricity (kt)	Heating Oil (kt)
Newfoundland	n/a	21	550
Prince Edward Island	n/a	5	160
Nova Scotia	n/a	410	800
New Brunswick	21	670	460
Québec	1,500	550	5,100
Ontario	14,200	2,000	2,700
Manitoba	1,200	160	29
Saskatchewan	340	250	16
Alberta	1,600	700	n/a
British Columbia	4,200	330	100
Territories	6	3	102
Total			

Annual Operational Savings

In addition to GHG reductions, GSHP systems also achieve substantial operating savings. Widespread use of GSHPs in Canada attests to their economic viability in heating dominated climates with relatively low electrical costs (Phetteplace 2007). The majority of regions display moderate to large annual savings in operating costs relative to the other available heating options (Figure 3)[8]. Homes in Newfoundland, Nova Scotia, New Brunswick, Ontario, and the Territories achieve annual savings in excess of $1,000 irrespective of which conventional fuel GSHPs are compared to. Relative cost of natural gas and electricity determine the financial payoffs in the remaining provinces. Some regions do not offer either natural gas or heating oil as a mainstream heating option and, therefore, provincial-level data on fuel costs are not available.

[8] Natural gas and electricity prices are current as of May 2007.

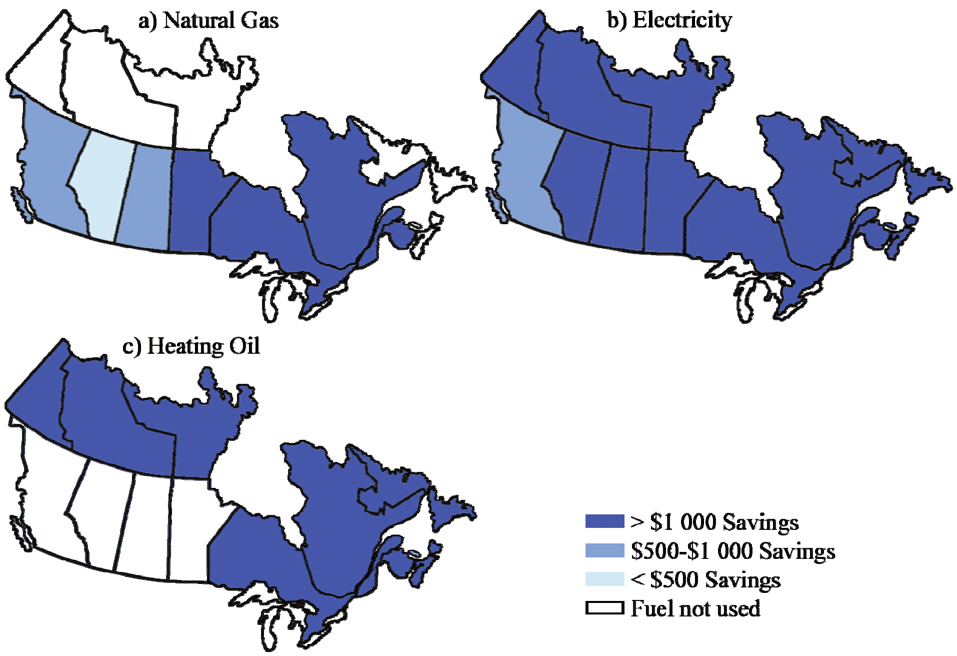


Figure 3. Annual Savings of GSHP Relative to Three Main Fuels, by Region

A more detailed description of savings in each region relative to conventional systems is available in Table 7. Shaded cells identify conventional fuels that are most suitable for a transition to GSHP due to the region's GHG-reduction potential (Table 6). In many provinces, we find a correlation between the fuel providing the largest GHG-reduction potential and largest annual operating savings. Since COPs are one of the most significant parameters influencing operating savings, we conduct a sensitivity analysis of heat pump efficiencies relative to natural gas, electric, and heating oil fuel options (Appendix B).

Table 7. Annual Operating Savings of GSHP Systems versus Other Fuels, by Region ($140m^2$ home, COP=4)

	Annual Savings ($)		
	Natural Gas	Electricity	Heating Oil
Newfoundland	n/a	1,600	1,700
Prince Edward Island	n/a	1,400	900
Nova Scotia	n/a	1,500	1,500
New Brunswick	1,100	1,600	1,800
Québec	1,900	1,500	2,300
Ontario	1,100	1,100	2,100
Manitoba	1,100	1,100	n/a
Saskatchewan	600	1,900	n/a
Alberta	500	2,500	n/a
British Columbia	800	900	n/a
Territories	n/a	2,000	1,100

Additional Capital Investments

Although low operating and maintenance costs mean that GSHP systems generally have attractive life-cycle costs, the initial investment costs of the systems are critical for the economical competitiveness of GCHP systems (Diao et al. 2004). In order to assess the financial viability of these systems, for each region (i.e., Ontario[9]) we discount the annual operational savings to obtain breakeven thresholds for payback periods of 5, 10, and 20 years (Figure 3). Detailed analyses of other provinces are available in Table 8.

If we aim for a 5-year payback with a discount rate of 7.5 percent, then the breakeven threshold of a COP 4 system occurs at $4,600 above the cost of a natural gas and air conditioning system; this increases to $4,800 at a COP of 5. Variations in discount rates have little influence on financial feasibility over a 5-year period. However, if we consider a 20-year payback period, the chosen discount rates significantly affects the breakeven threshold; varying the rate by plus or minus 2.5 percent yields fluctuations of approximately $4,000. A 20-year payback period also significantly increases the upper limit of allowable incremental capital costs; at this timeframe, a GSHP system could cost over $14,000 more and still provide savings for the homeowner.

[9] Ontario homes conventionally heated with natural gas comprise the most significant category to target for GSHP adoption due their cumulative emission-reduction potential of 14Mt of CO_{2eq} (Table 6).

We include a range of COPs to demonstrate the relationship between the breakeven thresholds costs and GSHP efficiency. Older GSHP technology provides an average COP of 3.5, while new GSHP technology under ideal conditions can perform at COPs higher than 5. Our study aims to assist in decision making by illustrating tradeoffs between a higher COP (and therefore higher operational savings) and the associated capital investment increase. Investing in a system that operates at a COP of 5 in Ontario would make financial sense if the system's incremental costs do not exceed ~\$2,100 more than a COP 3 system (20 year period, discount rate = 7.5 percent, $140m^2$). Figure 4 includes a range of actual, incremental costs of a GSHP system designed for a $140m^2$ home in Ontario. Given these specifications, payback periods can be expected to occur within 7 to 13 years.[10] Breakeven thresholds vary across the country, as they are highly dependent on the relative costs of heating fuel and GSHP-related electricity; more detailed profiles of each region are outlined in Appendix C.

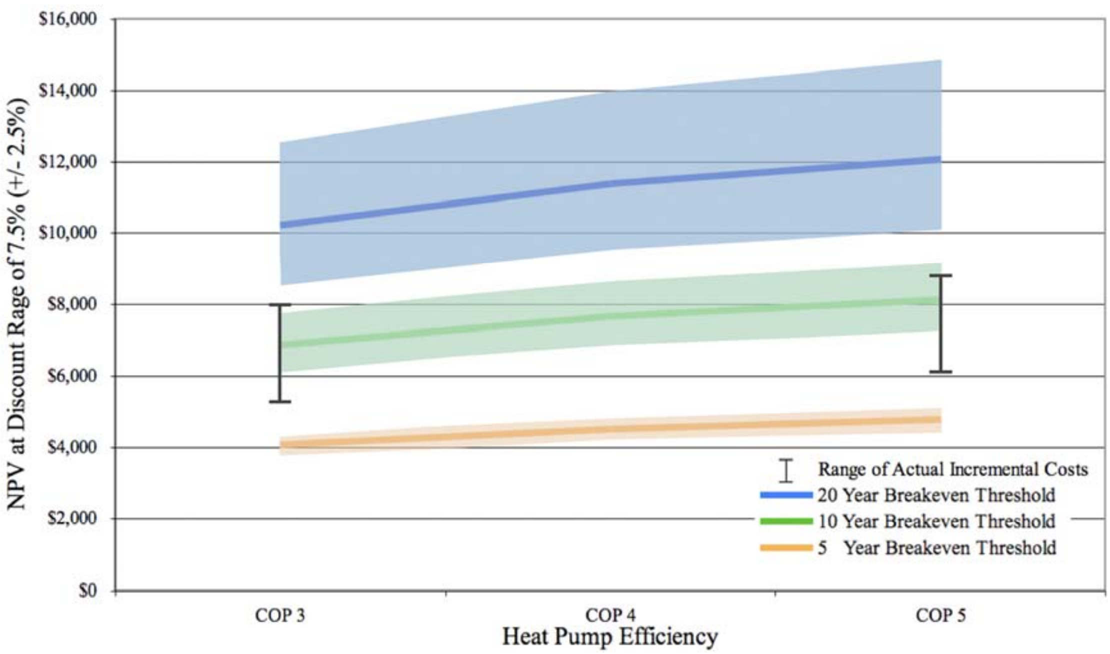


Figure 4. Net Present Value and Heat Pump Efficiencies for Three Payback Periods in Ontario

[10] GSHP costs are site specific. Horizontal loops in soils with ideal thermal properties reduce costs by up to 35 percent.

Table 8. Breakeven Thresholds of Incremental Capital Costs Associated with GSHP Systems for 5- and 20-year Payback Periods, by Province (140 m^2 home)[11]

	Natural Gas ($)		Electricity ($)		Heating Oil ($)	
Breakeven Threshold	5 Years	20 Years	5 Years	20 Years	5 Years	20 Years
Newfoundland	n/a	n/a	6,600	16,500	6,900	17,300
Prince Edward Island	n/a	n/a	5,700	14,300	3,600	9,100
Nova Scotia	n/a	n/a	6,100	15,300	6,000	15,200
New Brunswick	4,500	11,400	6,700	16,700	7,400	18,800
Québec	7,800	19,700	6,100	15,300	9,400	23,700
Ontario	4,600	11,600	4,500	11,400	8,400	21,100
Manitoba	4,300	10,800	4,500	11,400	n/a	n/a
Saskatchewan	2,200	5,600	7,800	19,600	n/a	n/a
Alberta	2,000	5,000	10,000	25,300	n/a	n/a
B.C.	3,300	8,200	3,500	8,700	n/a	n/a
Territories	n/a	n/a	8,000	20,400	4,600	11,500

Fuel Price Escalation and Operational Savings

We also take into account possible fuel price-increase scenarios, as GSHP systems require electricity. Rising electricity costs and stable heating fuel prices would result in lower operational savings; alternatively, high fossil fuel price increases would increase the economic viability of GSHPs. Figure 5 illustrates several permutations of fossil fuel and electricity price interactions over a 10-year timeframe. Case A represents a situation where both the heating oil and electricity prices remain constant. Case B demonstrates the effects of a three percent heating oil price increase and a two percent electricity cost increase.

Due to the efficiency ranges of GSHP systems, electricity price increases have a less pronounced effect on annual operating savings than fuel price increases. For instance, a three percent natural gas price increase in Ontario (at constant electricity prices) would increase GSHP annual operating savings by ~$550/year. However, a three percent electricity price increase would cause a ~$160/year reduction of operational savings at constant natural gas prices. Detailed information for all provinces and permutations of fuel price increases is shown in Appendix C (Tables C1–C3).

[11] To obtain the threshold increment for a 10-year payback period, we multiply the 5-year threshold value by a factor of 1.7, and to obtain the threshold for a 15-year period, we use a factor of 2.2.

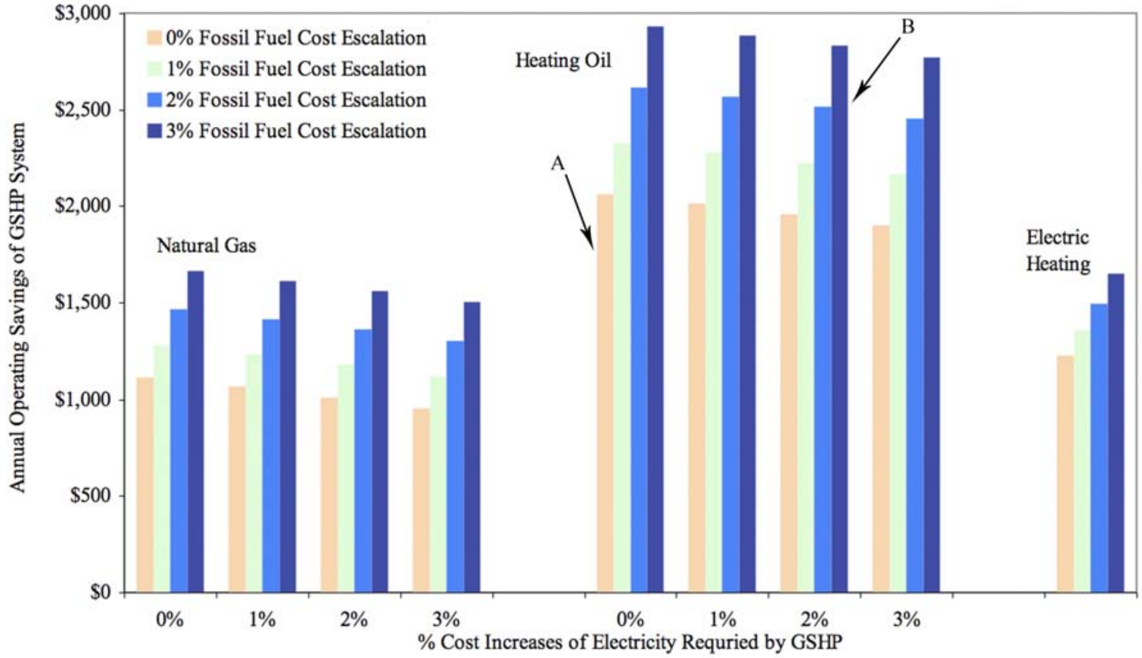


Figure 5. The Effect of Heating Fuel Price Increase Scenarios on Operating Savings of GSHP Systems in Ontario

Larger Home Sizes

NRCan's Survey of Household Energy provides empirical evidence that larger homes have lower energy intensity than smaller homes (NRCan 2005b); therefore, we extend the analysis to include the 27 percent of Canadian homes that are larger than 140 m^2. For instance, homes larger than 232 m^2 use 77 percent of the energy intensity the average house; this energy intensity adjustment is reflected in our calculations for larger homes. GSHP installations currently are most attractive to owners of larger homes because the payback periods are significantly reduced due to larger annual operating savings and because the capital investment required for GSHP also may be more readily available. The environmental benefits also increase; houses twice the average area (280 m^2) have higher heating and cooling loads, which in turn translates into larger emissions reductions through the use of a GHSP system.

Currently, the majority of GSHP installations are attributable to owners of larger homes. Table 9 outlines the emissions savings and annual operational savings of a 280 m^2 home, while Table 10 summarizes the breakeven thresholds for three different timeframes (COP = 4, discount rate = 7.5 percent). The higher annual operational savings of larger homes translate into shorter payback periods and, therefore, larger breakeven thresholds.

Table 9. Tons of CO_2 Averted and Annual Operating Savings for a GSHP System in a 280 m^2 Home, by Province

	Natural Gas		Electricity		Heating Oil	
	GHG Savings (t)	Annual Operating Savings of GSHP ($)	GHG Savings (t)	Annual Operating Savings of GSHP ($)	GHG Savings (t)	Annual Operating Savings of GSHP ($)
Newfoundland	7.8	n/a	0.5	2,500	12.5	2,700
Prince Edward Island	3.5	n/a	9.3	2,000	7.2	1,500
Nova Scotia	1.7	n/a	15.0	2,300	5.6	2,400
New Brunswick	4.5	1,700	11.7	2,300	10.0	3,000
Québec	9.4	3,000	0.9	2,400	15.1	3,700
Ontario	6.6	1,700	6.2	1,800	11.5	3,300
Manitoba	7.9	1,600	2.8	1,700	12.5	n/a
Saskatchewan	2.1	900	24.9	3,000	7.9	n/a
Alberta	2.5	600	34.4	3,800	8.1	n/a
British Columbia	6.0	1,200	1.7	1,300	9.8	n/a
Territories	4.3	n/a	4.7	3,100	8.4	1,900

Table 10. Breakeven Thresholds of Incremental Capital Costs Associated with GSHP Systems for 5- and 20-year Payback Periods, by Province (280m^2 home)[12]

	Natural Gas ($)		Electricity ($)		Heating Oil ($)	
Breakeven Threshold	5 Years	20 Years	5 Years	20 Years	5 Years	20 Years
Newfoundland	n/a	n/a	10,100	25,500	11,000	27,800
Prince Edward Island	n/a	n/a	7,900	20,000	6,200	15,600
Nova Scotia	n/a	n/a	9,300	23,500	9,600	24,300
New Brunswick	7,100	17,800	9,500	23,900	12,100	30,400
Québec	12,200	30,600	9,900	24,900	14,900	37,500
Ontario	7,200	18,100	7,200	18,300	13,300	33,600
Manitoba	6,600	16,600	7,000	17,700	n/a	n/a
Saskatchewan	3,600	9,000	12,000	30,300	n/a	n/a
Alberta	2,600	6,500	15,500	39,000	n/a	n/a
British Columbia	4,900	12,300	5,400	13,500	n/a	n/a
Territories	n/a	n/a	12,500	31,400	7,500	19,000

[12] The provided values facilitate decisionmaking about GSHP feasibility based on a desired payback period (discount rate 7.5 percent). To obtain the threshold increment for a 10-year payback period, we multiply the 5-year threshold value by a factor of 1.7, and to obtain the threshold for a 15-year period, we use a factor of 2.2.

As the demand for GSHP systems continues to increase, economies of scale will reduce the costs. Competition within the field will drive the profit margins to become more similar to those found in other heating equipment industries, which in turn will make the technology more accessible the average-sized home. Once a critical mass of GSHP adoption has been reached, growth could be substantially greater than current patterns indicate (Peartree Solutions 2003).

Discussion

Averting the Need for Electricity Generation Capacity

GSHPs require electricity to provide heating and cooling services; however, this does not necessitate that electric utility corporations expand generation capacity or that regions rely more heavily on imports to meet the increased demand. Currently installed electric heating systems not only use electricity for space conditioning but most are compatible with GSHP systems. We therefore assess the extent to which each region is capable of supporting GSHPs based on the amount of electricity that could be made available by electrically heated homes gradually shifting toward GSHP adoption (Table 11).[13] In most regions, a significant percentage of the housing stock could adopt GSHPs without increasing overall capacity requirements. Due to the relatively small portion of electrically heated homes in Ontario (~10 percent), only 45 percent of homes could transition to GSHP without resorting to imports. However, if the excess in Québec were to compensate for the large natural gas-heated housing stock in Ontario, then Ontario homes could transition to GSHP without the need for further imports.

[13] Regions capable internally of supporting GSHP installations warrant the electricity intensity outlined in Table 4.

Table 11. Amount of Electricity Currently Used by Electric Heating Systems and the Percentage of Total Housing Stock That Could Convert to GSHP without Capacity Expansion or Imports, by Province

	Electricity Available – Electric Heating System Energy Use (GWh)	Percentage of Total Housing Stock Supplied by Available Energy (%)
Newfoundland	1,300	195
Prince Edward Island	15	10
Nova Scotia	700	65
New Brunswick	2,000	215
Québec	25,000	220
Ontario	11,600	45
Manitoba	2,100	105
Saskatchewan	400	20
Alberta	1,100	10
British Columbia	5,200	85
Territories	15	15

Performance, Surficial Geology, and Limiting Factors

A variety of system parameters and their integration affect the performance and financial feasibility of a GSHP system; these include proper design, sizing, and installation. A sequentially sensitive approach is also necessary, as it is prudent to establish the geological formation's thermal properties as accurately as possible before proceeding with design (Phetteplace 2007).

Geological and thermodynamic aspects that need to be taken into account during the site investigation process include soil/rock properties, groundwater saturation, temperature profiles, soil stability, and thermal diffusivity. An illustration of the complexities involved in this process can be observed in the Western Cordillera, where soil/rock intervals in a single borehole often vary greatly in terms of drilling difficulty and thermal properties (VEL Engineering & Hemmera Energy Inc. 2004).

Table 12 provides a crude assessment of existing surficial geology conditions to convey a general sense of the surficial geology of the major metropolitan areas of Canada. Surficial maps used for this analysis[14] are two-dimensional and do not characterize the depth and uniformity of the surficial materials in sufficient detail to estimate drilling costs (Compass Resource Management et al. 2005).

Table 12. Suitability of GSHP Based on Surficial Geology for Major Metropolitan Areas

City	Population[15] (million)	Fraction of City Area by Drilling Conditions			Most Common Rock Types
		Easy	Medium	Variable	
Toronto	4.7	44%	25%	31%	Dominated by sand and silt, and pebbly sand
Vancouver	2	41%	30%	29%	Sand and silt, sand and gravel, till
Montreal	1	37%	8%	55%	Till, sand and gravel, clay and silt
Calgary	1	25%	4%	71%	Dominated by till
Edmonton	1	78%	0%	22%	Dominant by silt to sand sized

Rock types are classified primarily by heterogeneity and represent very conservative estimated conditions. For instance, till is usually characterized as a straightforward to medium-difficulty drilling medium; however, due to its significant range in particle size, it was categorized as having variable drilling conditions. Clay, silt, clay and bedrock can be classified as providing straightforward drilling conditions, even though differing techniques need to be used (Compass Resource Management and MK Jaccard and Associates 2005). The American Society of Heating, Refrigerating and Air-Conditioning Engineers recommends site investigations and sample boreholes to objectively evaluate which type of geoexchange system is best suited to a site.[16]

[14] Surficial maps of cities were obtained from the Geological Survey Canada.

[15] Where available, the Central Metropolitan Area population Statistics Canada 2001 (Community Profiles).

[16] Horizontal-loop GSHP system costs are not affected by drilling conditions to a great extent.

GSHP Potential

Housing operation is the most energy- and CO_2-intensive among all consumer activities (Bin and Dowlatabadi 2005), while space conditioning and water heating are the largest components of housing operation in many societies (Baralas et al. 2004; Eriksson and Vamling 2006). GSHPs can provide these essential energy services at emissions reductions of 60 percent relative to the conventional fuel options.

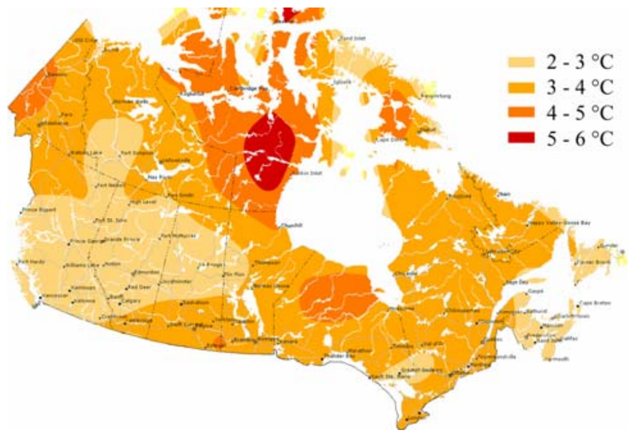
Despite increasing market share, GSHP systems continue have a large and currently unrealized GHG-reduction and financial savings potential across Canada. Maritime provinces and Québec could achieve emissions reductions of up to 7 Mt if GSHP systems were to replace heating oil. A similar transition from natural gas to GSHP in Ontario and the western provinces could yield emissions reductions of 21.4 Mt (Table 6).

Other priority locations for GSHP heating and cooling services include regions with large electric heating market shares and where electricity demand will soon surpass generation capacity. Furthermore, provinces that demonstrate high increases in electric space heating should also be targeted (Québec, Newfoundland, and New Brunswick; see Table 2). While federal jurisdiction over the energy market relates to international and inter-provincial trade and facilities, provincial governments are responsible for energy production and distribution within the province. Therefore, any regulatory initiatives to increase production of renewable energy must be undertaken at the provincial level (Islam, Fartaj, and Ting 2003). Commitment to emissions-reduction strategies can be demonstrated through the provision of provincial-level incentives for increased GSHP adoption as well as accountability for emissions embodied in inter-regional electricity trade.

Furthermore, provincial governments must also support infrastructure supporting the GSHP industry by addressing the current shortage of GSHP trades persons and installers. This could in part be achieved through sufficient funding for various accreditation processes and support for standardized system design requirements.

Climate Change Implications

As the effects climate change become more pronounced in Canada and summers become warmer, more homeowners will consider air conditioning essential. Figure 6 depicts the projected changes in summer temperature by 2050. Additionally, the future will bring increased demand for environmentally sound heating and cooling options. GSHP can not only meet the rising demand for increased comfort, but can achieve emissions reductions necessary to help stabilize climate change. The cumulative effect of a Canada-wide transition to GHSP heating and cooling would result in emissions reductions of 38 Mt of CO_{2eq} per year. This technology would result in emissions reductions of 62 percent with respect to current emissions associated with residential space conditioning and water heating.



Source: Atlas of Canada

Figure 6. Projected Changes in Candadian Summer Temperature by 2050

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Appendix A

GHG Intensities

Detailed electricity GHG intensities can be found in the Government of Canada Greenhouse Gas Inventory (2003). Using electricity trade data from the National Energy Board (2005), we found that the amount of electricity trade between provinces and the United States affects a region's CO_2 intensity. Incorporating these data are essential, as GHG electricity import intensities have an effect on the emissions associated with heat pump operation. We compare three possible methods of estimating a region's comprehensive emissions intensity; shaded cells indicate regions where a significant change in intensity occurs (Table A1). Emissions associated with heat pump operation in each province depend on whether we focus on electricity intensity of: 1) generated electricity and net imports; 2) the marginal units of electricity imported; or 3) the average carbon intensity of local generation and imports.

Table A1. Emission Intensities of Generated and Imported Electricity, by Province

Emission Intensity	Generation only (tCO_{2eq}/GWh)	(1) Generation and Imports–Exports (tCO_{2eq}/GWh)	(2) Net Imports Only (If Imports > Exports) (tCO_{2eq}/GWh)	(3) Generation and All Imports (tCO_{2eq}/GWh)
Newfoundland	21	21	21	21
Prince Edward Island	1,120	458	433	461
Nova Scotia	759	759	759	751
New Brunswick	433	433	433	435
Québec	8	17	66	28
Ontario	222	222	222	229
Manitoba	31	31	31	133
Saskatchewan	840	838	693	833
Alberta	861	857	585	844
British Columbia	24	35	507	82
Territories	249	249	249	249

Method 1 (Table A1) accounts for only the amount of net imported electricity. In a scenario where British Columbia (BC) and Alberta engage in electricity trade, and BC imports exceed those of Alberta, the carbon intensity of the only the net importer (BC) is affected. This

approach is often taken when calculating electricity related emissions in Prince Edward Island (PEI). The province imports 96 percent of its electricity from New Brunswick; its internal electricity intensity is extremely skewed and thus is not representative with the emissions resulting from PEI electricity use. Using this approach, a province can buy and sell carbon-intensive electricity, but its GHG intensity is only affected if imports exceed exports. The underlying assumption for Method A is that internally generated electricity is used up within the province, whereas purchased electricity is then sold. A province that generates clean electricity and purchases coal-generated electricity would then not be selling low-carbon electricity, but would be exporting the electricity and embodied carbon emissions that this province purchases.

Method 2 illustrates an approach where only the emissions embodied in marginal electricity imports are used to calculate the emissions associated with GSHP use. Using this methodology, PEI's electricity, for example, would be equivalent to that of New Brunswick's, since an additional heat pump unit would increase the requirement for imported electricity. Assumptions underlying this method include that provinces will continue to remain net importers of electricity or that the rate of shifting to GSHP and retrofitting electrically heated homes exceeds the number of homes currently heated with electricity.

Method C holds the province accountable for the GHG emissions from all the electricity it imports; the imported electricity then contributes to the overall emissions intensity of internally used and exported electricity. Method C is used in this article for GHG-related calculations and has been gaining support to encourage a province to assess the source of its electricity imports more critically. The values are representative of 2004 emissions; new capacity expansions in each region may not follow past patterns, as coal plants are planned in BC while wind and nuclear flourish in Ontario. The effects of imported electricity vary significantly by province, and our focus is on system-wide effects on GHG emissions-reduction opportunities through GSHP installations. A sensitivity analysis of the three methods and their effect on the overall GHG reductions for a 240m^2 home is provided in Table A2, while Table A3 outlines the calculations of Method C. In Table A2, an additional column (Gen) was added to illustrate the reductions associated with GSHP using the electricity intensity of generated electricity only.

Table A2. Sensitivity Analysis of Three GHG Intensity Methods Illustrating the Differences in Emissions Reduction Potential, by Province[17]

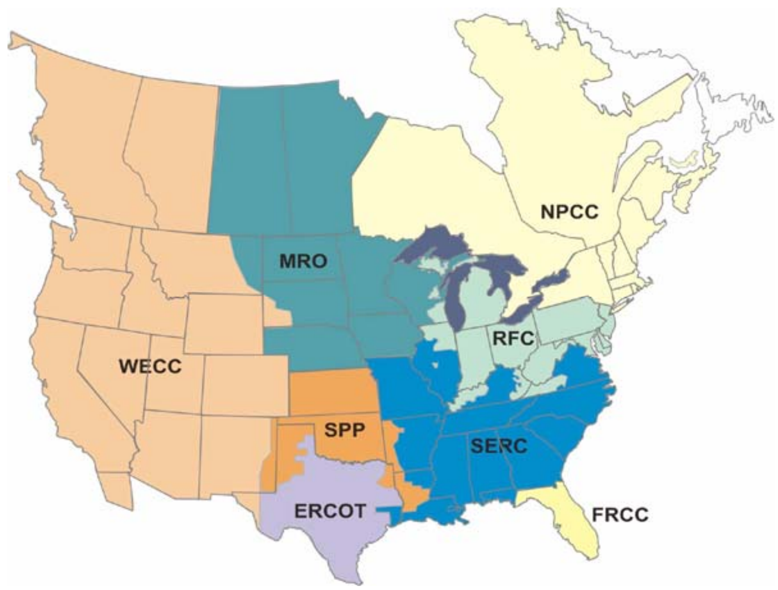
	Emissions Reductions of GSHP Relative to											
	Natural Gas (t)				Electricity (t)				Heating Oil (t)			
Method	Gen	(1)	(2)	(3)	Gen	(1)	(2)	(3)	Gen	(1)	(2)	(3)
Newfoundland	5.0	5.0	5.0	5.0	0.3	0.3	0.3	0.3	8.1	8.1	8.1	8.1
Prince Edward Island	-0.4	2.3	2.4	2.3	14.6	6.0	5.6	6.0	2.0	4.7	4.8	4.7
Nova Scotia	1.1	1.1	1.1	1.1	9.8	9.8	9.8	9.7	3.6	3.6	3.6	3.7
New Brunswick	2.9	2.9	2.9	2.9	7.6	7.6	7.6	7.6	6.5	6.5	6.5	6.5
Québec	6.2	6.2	5.9	6.1	0.2	0.3	1.3	0.6	9.9	9.9	9.6	9.8
Ontario	4.3	4.3	4.3	4.3	3.9	3.9	3.9	4.1	7.5	7.5	7.5	7.4
Manitoba	5.4	5.4	5.4	5.1	0.6	0.6	0.6	1.8	8.4	8.4	8.4	8.1
Saskatchewan	1.2	1.2	2.1	1.3	16.2	16.2	13.4	16.1	5.0	5.0	5.9	5.1
Alberta	1.4	1.5	3.7	1.6	22.8	22.7	15.5	22.3	5.1	5.1	7.4	5.2
British Columbia	4.1	4.1	2.2	3.9	0.3	0.5	6.7	1.1	6.6	6.6	4.6	6.4
Territories	2.8	2.8	2.8	2.8	3.1	3.1	3.1	3.1	5.5	5.5	5.5	5.5

[17] Note that PEI's internally generated electricity accounts for 4 percent of total energy consumption, therefore PEI's electricity intensity is generally not used for GHG emissions calculations.

Table A3. Electricity GHG Intensities Adjusted to Include Imported Electricity, by Province

	Emission Intensity (t/GWh)	Generation (GWh)	Import Source	Imports (GWh)	Total Energy (GWh)	Adjusted Intensity (t/GWh)
Newfoundland	**21**	**43,599**	Québec	**16**	**43,615**	**21**
PEI	**1,120**	**49**	New Brunswick	**1,124**	**1,173**	**464**
Nova Scotia			New Brunswick	268		
			US	40		
	759	**11,624**	**Total**	**308**	**11,932**	**751**
New Brunswick			Québec	66		
			US	44		
			Nova Scotia	216		
	433	**19,295**	**Total**	**326**	**19,621**	**433**
Québec			Ontario	9,086		
			US	3,459		
			New Brunswick	1,248		
			Newfoundland	29,750		
	8	**174,951**	**Total**	**43,543**	**218,494**	**31**
Ontario			Manitoba	1,539		
			US	7,887		
			Québec	3,209		
	222	**155,847**	**Total**	**12,635**	**168,482**	**274**
Manitoba			Saskatchewan	190		
			US	2,555		
			Ontario	84		
	31	**32,501**	**Total**	**2,829**	**35,330**	**132**
Saskatchewan			Alberta	328		
			US	1,083		
			Manitoba	326		
	840	**17,488**	**Total**	**1,737**	**19,225**	**833**
Alberta			British Columbia	1,145		
			US	367		
			Saskatchewan	641		
	861	**60,443**	**Total**	**2,153**	**62,596**	**891**
British Columbia			US	7,000		
			Alberta	951		
	24	**61,951**	**Total**	**7,951**	**69,902**	**80**
Territories	**249**	**1,049**	**N/A**	**N/A**	**1,041**	**255**

The North American Electric Reliability Council Electricity facilitates U.S. electricity imports into Canada (Figure A1). BC and Alberta purchase electricity from the Western Electricity Coordinating Council (WECC), Saskatchewan and Manitoba import from the Midwest Reliability Organization (MRO), while the eastern provinces trade with the Northeast Power Coordinating Council (NPCC). Emissions intensities used in this study for electricity imports from WECC, MRO and NPCC areas are listed in Table A4.



Source: NERC

Figure A1. North American Electricity Reliability Council Regions

Table A4. Emission Intensities of the North American Electricity Reliability Council Regions

Region	WECC	MRO	NPCC
Total Generation (GWh)	667,200	179,000	254,600
Total Emissions (t)	338,417,000	164,557,000	119,864,000
Emission Intensity (t/GWh)	507	919	471

Source: U.S. Environmental Protection Agency (2003).

Appendix B

Table B1. Coefficient of Performance Influence on Annual Operating Savings Relative to Natural Gas, by Region

	Annual Operating Savings ($)				
Coefficient of Performance	COP 3	COP 3.5	COP 4	COP 4.5	COP 5
New Brunswick	900	1,000	1,100	1,200	1,200
Quebec	1,800	1,800	1,900	1,900	2,000
Ontario	1,000	1,100	1,100	1,200	1,200
Manitoba	900	1,000	1,100	1,100	1,100
Saskatchewan	300	500	600	600	700
Alberta	200	400	500	600	700
British Columbia	700	800	800	800	900

Note: Excluces regions where natural gas is not commonly used.

Table B2. Coefficient of Performance Influence on Annual Operating Savings Relative to Electric Heating, by Region

	Annual Operating Savings ($)				
Coefficient of Performance	COP 3	COP 3.5	COP 4	COP 4.5	COP 5
Newfoundland	1,400	1,500	1,600	1,700	1,700
Prince Edward Island	1,200	1,300	1,400	1,500	1,500
Nova Scotia	1,300	1,400	1,500	1,600	1,600
New Brunswick	1,500	1,600	1,600	1,700	1,800
Québec	1,400	1,400	1,500	1,500	1,600
Ontario	1,000	1,100	1,100	1,200	1,200
Manitoba	1,000	1,100	1,100	1,200	1,200
Saskatchewan	1,700	1,800	1,900	2,000	2,000
Alberta	2,200	2,400	2,500	2,600	2,600
British Columbia	800	800	900	900	900
Territories	1,800	1,900	2,000	2,100	2,100

Table B3. Coefficient of Performance Influence on Annual Operating Savings Relative to Heating Oil, by Region

	Annual Operating Savings ($)				
Coefficient of Performance	COP 3	COP 3.5	COP 4	COP 4.5	COP 5
Newfoundland	1,500	1,600	1,700	1,800	1,800
Prince Edward Island	700	800	900	1,000	1,000
Nova Scotia	1,300	1,400	1,500	1,500	1,600
New Brunswick	1,700	1,800	1,800	1,900	2,000
Québec	2,200	2,300	2,300	2,400	2,400
Ontario	2,000	2,000	2,100	2,100	2,100
Territories	900	1,000	1,100	1,200	1,300

Note: Excludes regions where heating oil is not commonly used.

Appendix C

Table C1. Annual Operating Savings: Natural Gas and GSHP-related Electricity Cost Comparison Matrix, by Province

Natural Gas Cost Escalation		Operating Savings at Various Electricity Rate Increases ($)			
		0%	1%	2%	3%
New Brunswick	0%	1,100	1,000	900	800
	1%	1,300	1,200	1,100	1,000
	2%	1,500	1,500	1,400	1,300
	3%	1,800	1,700	1,600	1,500
Québec	0%	1,900	1,900	1,800	1,700
	1%	2,200	2,100	2,100	2,000
	2%	2,500	2,400	2,400	2,300
	3%	2,800	2,700	2,700	2,600
Ontario	0%	1,100	1,100	1,000	1,000
	1%	1,300	1,200	1,200	1,100
	2%	1,500	1,400	1,400	1,300
	3%	1,700	1,600	1,600	1,500
Manitoba	0%	1,100	1,000	1,000	900
	1%	1,200	1,200	1,100	1,100
	2%	1,400	1,300	1,300	1,200
	3%	1,600	1,500	1,500	1,400
Saskatchewan	0%	600	500	400	300
	1%	700	600	500	400
	2%	800	700	700	600
	3%	1,000	900	800	700
Alberta	0%	500	400	300	200
	1%	600	500	400	300
	2%	800	700	600	500
	3%	1,000	900	800	700
British Columbia	0%	800	800	700	700
	1%	900	900	800	800
	2%	1,000	1,000	1,000	900
	3%	1,200	1,100	1,100	1,100

Note: Excludes region where natural gas is not commonly used.

Table C2. Annual Operating Savings: Electric Heating and GSHP-related Electricity Cost Comparison Matrix, by Province

	Operating Savings at Various Electricity Rate Increases ($)			
	0%	1%	2%	3%
Newfoundland	1,600	1,800	2,000	2,200
Prince Edward Island	1,400	1,500	1,700	1,900
Nova Scotia	1,500	1,700	1,800	2,000
New Brunswick	1,600	1,800	2,000	2,200
Québec	1,500	1,700	1,800	2,000
Ontario	1,100	1,200	1,400	1,500
Manitoba	1,100	1,200	1,400	1,500
Saskatchewan	1,900	2,100	2,300	2,600
Alberta	2,500	2,700	3,000	3,300
British Columbia	900	900	1,000	1,200
Territories	2,000	2,200	2,400	2,700

Table C3. Annual Operating Savings: Heating Oil and GSHP-related Electricity Cost Comparison Matrix, by Province

Heating Oil Cost Escalation		Operating Savings at Various Electricity Rate Increases ($)			
		0%	1%	2%	3%
Newfoundland	0%	1,700	1,600	1,500	1,400
	1%	1,900	1,900	1,800	1,700
	2%	2,200	2,100	2,100	2,000
	3%	2,500	2,500	2,400	2,300
Prince Edward Island	0%	900	800	700	600
	1%	1,100	1,000	900	800
	2%	1,300	1,200	1,100	1,000
	3%	1,500	1,400	1,300	1,200
Nova Scotia	0%	1,500	1,400	1,400	1,300
	1%	1,700	1,600	1,600	1,500
	2%	2,000	1,900	1,800	1,700
	3%	2,200	2,200	2,100	2,000
New Brunswick	0%	1,800	1,800	1,700	1,600
	1%	2,100	2,000	1,900	1,800
	2%	2,400	2,300	2,200	2,100
	3%	2,800	2,700	2,600	2,500
Québec	0%	2,300	2,300	2,200	2,100
	1%	2,600	2,600	2,500	2,400
	2%	2,900	2,900	2,800	2,800
	3%	3,300	3,200	3,200	3,100
Ontario	0%	2,100	2,000	2,000	1,900
	1%	2,300	2,300	2,200	2,200
	2%	2,600	2,600	2,500	2,500
	3%	2,900	2,900	2,800	2,800
Territories	0%	1,100	1,000	900	800
	1%	1,300	1,200	1,100	1,000
	2%	1,600	1,500	1,400	1,200
	3%	1,800	1,700	1,600	1,500

Note: Excludes regions where heating oil is not commonly used.