ELECTRIFYING RESIDENTIAL SPACE HEATING WITH AIR-SOURCE HEAT PUMPS IN A CARBON-INTENSIVE GRID: GREENHOUSE GAS EMISSION IMPACTS AND THE CASE OF INCENTIVISING IN NOVA SCOTIA

by

Mickey Gilchrist

Submitted in partial fulfillment of the requirements
for the degree of Master of Environmental Studies

at

Dalhousie University
Halifax, Nova Scotia
January 2019

Table of Contents

List of Tables

List of Figures

Abstract

Commitments to reduce greenhouse gas (GHG) emissions warrant consideration of alternative residential space heating technologies particularly in regions with colder climates. The Canadian province of Nova Scotia (NS) has relied heavily on home heating oil (HHO) for residential space heating compared to the rest of Canada, accounting for two-thirds of total residential provincial emissions. Displacing HHO with highly efficient cold climate air-source heat pumps (HPs) has been shown in other regions to reduce GHG emissions if the supply of electricity is from clean renewable sources. Although NS has made considerable progress in recent years to increase renewable electricity generation, the province still relies heavily on fossil fuels and is amongst the highest in Canada in terms of emissions intensity. Some estimates indicate that HPs are gaining in market share in NS and the province is incentivising the transition through multiple funding sources. However, does it make sense to displace HHO with a HP to reduce GHG emissions, considering the still relatively high carbon-intensive electricity grid in NS? Furthermore, does the transition make sense to the individual homeowner in terms of operating costs and net overall investment savings? Scenario analysis estimates that displacing HHO with a HP in NS in 2017 can reduce GHG emissions to the province cumulatively and to the individual household, but the net savings of the investment is highly variable based on the individual's situation. That is, the net savings of a HP investment to displace HHO is highly variable due to the individuals household characteristics, borrowing costs, and also due to what is known as the energy efficiency gap, a well-researched phenomenon that attempts to explain why seemingly economically beneficial investments in energy efficiency do not occur as expected. Sensitivity analysis are presented assessing the impacts of HP and HHO performance, fuel price fluctuations, borrowing costs and discount rates to account for variability among individuals. This research confirms the potential to reduce GHG emissions in NS today by displacing HHO with HPs for residential home heating, and the potential becomes even greater into the future as the provinces electricity supply is anticipated to include more renewables. This research also demonstrates the highly variable net investment savings to the individual, which provides implications for policy design in regard to encouraging the uptake of HPs in NS.

List of Abbreviations and Symbols Used

ACCA:	Air Conditioning Contractors of America
AFUE:	Annual fuel utilization efficiency
CAT:	Climate Action Tracker
CEUDH:	Canada’s Energy Use Data Handbook
CMHC:	Canadian Mortgage and Housing Corporation
Co:	total initial investment costs of HP
CO_2e:	Carbon dioxide equivalent
COMFIT:	Community feed-in tariff
COP:	Coefficient of performance
COP21:	21st Conference of the Parties
CSA:	Standards Council of Canada
Ct:	net cash inflow (savings) of operating HP each year
DEAP:	Dwelling Energy Assessment Procedure
EGSPA:	Environmental Goals and Sustainable Prosperity Act
EHPA:	European Heat Pump Association
EU:	European Union
EUEC:	European Union Energy Commission
ENS:	Efficiency Nova Scotia
ETS:	Electric thermal storage
EV:	Electric vehicle
GH:	Green Heat (Efficiency Nova Scotia incentive program)
GHG:	Greenhouse gas emissions
gCO_2e:	Grams of carbon dioxide equivalent
GSHP:	Ground source heat pump
GWP:	Global warming potential
HDD:	Heating degree-days
HEA:	Home Energy Assessment (Efficiency Nova Scotia incentive program)
HHO:	Home heating oil
HP:	Air-source heat pump (central & mini-split, air-to-air; air-to-water)
IEA:	International Energy Agency
IRR:	Internal Rate of Return
kW:	Kilowatt
kWh:	Kilowatt hour

LCEF:	Low Carbon Economy Fund
INDCs:	Intended Nationally Determined Contributions
MW:	Megawatts
NDCs:	Nationally Determined Contributions
NEEP:	Northeast Energy Efficiency Partnerships
NIR:	National Inventory Report
NPV:	Net Present Value
NRCan:	Natural Resources Canada
NRTEE:	Canadian National Round Table on the Environment and Economy
NS:	Nova Scotia
NSP:	Nova Scotia Power Inc
NSUARB:	Nova Scotia Utility and Review Board
PBO:	Office of the Canadian federal Parliamentary Budget Officer
PCF:	Pan-Canadian Framework on Clean Growth and Climate Change
r:	discount rate
T:	number of time periods (15 years)
tCO$_2$e:	Tonnes of carbon dioxide equivalent
The Gap:	The energy efficiency gap
UNFCCC:	United Nations Framework Convention on Climate Change

Chapter 1: Introduction

The need to reduce greenhouse gas (GHG) emissions to mitigate climate change risks are of increasing urgency (IPCC, 2014). Many countries are lagging both in targets and the commitments deemed necessary to limit global temperature rise to below 2°C above pre-industrial levels, the main goal agreed upon at the Conference of the Parties in 2015 (CAT, 2017b; UNFCCC, 2016c). Strategies to achieve significant emissions reductions are unique to each jurisdiction, but are generally targeted at large energy sinks; electricity generation, heat generation and transportation (IEA, 2017). Renewable electricity generation is growing in capacity and price-competitiveness to conventional electricity production in many jurisdictions (IRENA, 2018). Therefore, a shift towards electrification for space heating and transportation is starting to make sense in many jurisdictions as a strategy for long-term emissions reductions in the energy sector (Jacobsen, et al., 2015; Dennis, 2015; Mahone, et al., 2015). Such a shift towards renewable generation and electrification of heating and transportation can also increase energy security in a region, as it reduces its dependency on fossil fuel imports from potentially volatile international markets (Hughes, 2012).

Nova Scotia (NS) is a carbon intensive province within Canada that still generates a considerable proportion of its electricity from fossil fuels, but is in the process of transitioning to cleaner renewable generation (NSP, 2016c). Through legislation, the Province has imposed “hard caps” on the regulated electric utility (Nova Scotia Power) that have increasingly strict limits on emissions from 2015 to 2030, and is expected to result in the largest emissions reductions in the province (NS DOE, 2015c). In addition to reducing electricity generation emissions, NS is also looking to energy efficiency to reduce overall emissions, particularly in some of the largest emissions-source sectors in the province: transportation and space heating (NEB, 2016).

Residential space heating in NS provides a greater opportunity for emissions reduction compared to the rest of Canada due to its older housing stock, lack of affordable and accessible natural gas, and consequent reliance on home heating oil (HHO) (NRCan, 2015c). In addition, the emerging efficiency-gains of cold-climate air source heat pump (HP) technology have shown to reduce emissions and operating costs when displacing HHO in climates like NS (NEEP, 2017a; NEEP, 2014; Matley, 2013). With the recent announcement of federal funding for incentive programs aimed at homes heated with HHO - a segment of the home population previously excluded from heating system rebates (Chronicle Herald, 2017) - it would appear the province is well-positioned for a heating sector transition from HHO to HPs. Transitioning the heating sector in NS from HHO to HPs can potentially increase energy security; it also supports larger goals of electrification (Jacobsen, et al., 2015; Dennis, 2015; Mahone, et al., 2015). However, does the transition to HPs make sense in terms of emissions reductions considering the province still relies heavily on fossil fuel generated electricity?

Heat pumps require electricity to operate, so the GHG emissions that result from HP use will largely depend on the generation source of electricity. Currently, 95% of Nova Scotians get their electricity from Nova Scotia Power (NSP), the privately owned, regulated electric utility monopoly (NSP, 2017e), so in nearly all cases, the GHG emissions produced from operating a HP in the Province will depend on NSP generated emissions. NSP emissions have been improving significantly in recent years, mainly due to investments in renewable energy (NS DOE, 2015c), prompted in large part by emission reduction requirements imposed by the Province (Greenhouse Gas Emissions Regulations, 2009). Despite these recent improvements, the average GHG emissions intensity[1] of NSP generated electricity remains high at 700 grams of

---

[1] The ratio of GHG emissions produced (grams of CO_2e) per electricity generated (kWh)

carbon dioxide equivalent (gCO_2e)/kilowatt hour (kWh) as of 2016 (NSP, 2016b) compared to the national average of 140 gCO_2e /kWh in 2016 (ECCC, 2018a). In addition, modern HHO systems operate extremely efficiently, transferring 98.5% of thermal energy released through combustion to space heating (USDOE, 2017a). Therefore, it remains unclear if the switch to HPs for residential home heating in NS will reduce GHG emissions.

It is also unclear if displacing HHO with HPs for residential heating in NS will result in a net positive savings for the individual household. That is, will the present discounted value of future operating cost savings of the HP exceed the upfront capital costs of the HP installation and lifetime borrowing costs? The efficiency advantages of HPs are expected to decrease operating costs when displacing HHO in regions like NS (NEEP, 2017a; Matley, 2013); but these operating cost savings are highly variable at the individual homeowner level. The upfront capital costs of installation and borrowing costs will vary among individuals, and also with the equipment performance, usage, and maintenance costs (Gillingham & Palmer, 2014). In addition, non-financial costs such as hidden costs (the perceived cost of time to learn about various HP options and locate a suitable contractor) and uncertainty (equipment performance) will vary highly among individuals (Giraudet & Houde, 2015; Michelsen & Madlener, 2015; Clinch & Healy, 1999).

Often these non-financial costs are overlooked in a cost-benefit analysis of a HP investment, resulting in an overstated expectation of net overall savings (Giraudet & Houde, 2015; Michelsen & Madlener, 2015; Clinch & Healy, 1999). Overstated savings have consistently been linked to lower than expected investment in HPs and energy efficiency in general (Gillingham & Palmer, 2014), and has led to what is known as the energy efficiency gap (*the Gap*). *The Gap* is a well-researched phenomenon that attempts to explain why seemingly economically beneficial investments in energy efficiency (including HPs) do not occur as expected (Allcott, Mullainathan, & Taubinsky, 2014; Gillingham & Palmer, 2014; Jaffe & Stavins, 1994); it is likely present in NS. Therefore, it is unknown if displacing HHO with a HP will result in a net positive savings to the individual household, while accounting for varying costs and the potential existence of *the Gap* in NS.

1.1 Research Objectives and Questions

This research will assess the estimated performance of HPs relative to HHO in terms of GHG emissions, cumulatively, at the provincial scale, and the scale of the typical individual household. The time-period considers “today” – and over the next 25 years as the GHG emission intensity of electricity in NS is expected to decline. In addition, a cost-benefit analysis is presented for the individual homeowner, to understand the potential uptake of HPs in NS – assuming consumers will invest in a HP to displace HHO if the lifetime savings are greater than the upfront and lifetime costs, and while accounting for individual variances in the time value of money.

This research focuses on displacing HHO entirely with air-source heat pumps, which consist of air-to-air and air-to-water, and have defined all as simply HPs. Heat pumps that extract thermal energy from the air are far more common than ground-source heat pumps for residential home heating (NEEP, 2017a; NRCan, 2017a; NEEP, 2014) and are the most logical choice when the existing heating source must be replaced or retrofitted to work in conjunction with existing heating infrastructure in a home, as they are cheaper and easier to install (USDOE, 2017b). Specifically, the goals of this research are to quantify:

1. The net annual GHG emissions impact if all residential homes space heating with HHO in 2017 were converted instantaneously to an electric air-source HP in NS.

2. The net annual GHG emissions and operating cost impacts for typical individual residential homes in NS, who displace HHO with HPs for space heating in 2017.
3. The energy consumption, operating cost and emission impacts over the next 25 years, for individual residential homes in NS, who displace HHO with a HP for space heating.
4. The proportion of homes in NS, which would return net positive savings (Net Present Value [NPV] & Internal Rate of Return [IRR]) from a HP investment to displace HHO.

The results of this research should be of interest to policy makers, consumers, and private stakeholders, as it deals with the potential impacts of electrifying residential heating with HPs, in a cold-climate, carbon-intensive province that has traditionally relied on HHO. In addition, this research will provide insight on the appetite of individual homeowners to invest in a HP to displace HHO, assuming the present discounted value of future savings exceeds the upfront and lifetime borrowing costs the HP.

1.2 Thesis Organization

This thesis is organized in six chapters:

- The current chapter provides the preliminary context of the research and research questions.
- Chapter Two provides a thorough literature review on the context for displacing HHO in NS with HPs for residential heating, in terms of contributing to near and long-term GHG emissions reductions, and reducing space heating costs to the individual home.
- Chapter Three outlines the data collection and methodology used to quantify both the GHG emission implications and the investment costs of displacing HHO with HPs in NS. This includes the use of scenario analysis and evaluation and sensitivity testing where uncertainties exist.

- Chapter Four presents the results of the scenario analyses.
- Chapter Five presents a synthesis of the results and offers insights on the broader implications.
- Chapter Six provides concluding remarks and recommendations for applying the findings. It also highlights the gaps identified by this research and offers suggestions for future work.

Chapter 2: Literature Review

2.1 Climate Change

The implications of climate change are increasingly being recognized as complex and far-reaching, creating global challenges with heightened sense of uncertainty and unpredictability (NASA, 2018; Cook, et al., 2016; IPCC, 2014). Consistent evidence suggests that anthropogenic greenhouse gas (GHG) emissions linked to economic and population growth are currently the highest in history, which has led to atmospheric concentrations unparalleled in at least the last 800,000 years (NASA, 2018; Cook, et al., 2016; IPCC, 2014; Karl, Melillo, & Peterson, 2009). This has resulted in various negative effects that are evident across the globe, and is accepted to be the likely dominant cause of the observed global warming since the mid-20th century (NASA, 2018; Cook, et al., 2016; IPCC, 2014). These unprecedented changes to the climate pose significant risks to human health, security, and economic growth; the impacts are being felt today (ECCC, 2017a; PCF, 2016; IPCC, 2014). With emission rates continuing to rise, it is likely that the frequency of heat waves and extreme precipitation, or lack thereof, will increase, becoming more intense, while global mean sea levels and ocean acidification rise, thus amplifying existing risks and creating new risks for natural and human systems (NASA, 2018; Cook, et al., 2016; IPCC, 2014; Karl, et al., 2009). To avoid such impacts to both people and ecosystems, countries are setting more ambitious emissions reduction targets and reporting annual progress under a globally accepted system for emissions reporting, for ease of communication (UNFCCC, 2016a)

To enable international monitoring and accounting, a standard system of GHG emissions reporting has been developed based on the six main GHG's including: carbon dioxide (CO_2); methane (CH_4); nitrous oxides (N_2O); hydrofluorocarbons (HFC); perfluorocarbons (PFCs); and sulphur hexafluoride (SF_6) (UNFCCC, 2016a). Greenhouse gases trap heat in the earth's atmosphere in a way similar to how the glass of a greenhouse contains heat, and thus, contributes to global warming and climate change more generally (ECCC, 2017a). Different GHG's absorb heat to varying degrees and remain in the atmosphere for varying durations, so the emissions of one tonne of carbon dioxide released to the atmosphere will have a different impact to one tonne of methane or nitrous oxide released (Table 1) (NSP, 2016a). As a result, different GHG's are said to have different global warming potentials (GWP) and are consequently assigned different GWP weighting values to permit their comparison, more effective and consistent communication, and to allow aggregation of multiple emissions into a single unit of impact: CO_2 equivalent emissions (CO_2e) (ECCC, 2017c; UNFCCC, 2016a; IPCC, 2012). This creates a convenient measure for interested stakeholders to compare the relative climate impacts of different sources of emissions.

Table 1. Global Warming Potential Values for the Main Greenhouse Gases —100 Year Time Horizon (ECCC, 2017c; UNFCCC, 2016a; IPCC, 2012)

Greenhouse Gas	Global Warming Potential
Carbon Dioxide (CO_2)	1
Methane (CH_4)	25
Nitrous Oxide (N_2O)	298
Sulphur hexafluoride (SF_6)	22,800
Hydrofluorocarbons (HFCs) 13 species	92 – 14,800
Perfluorocarbons (PFCs) 7 species	7,390 – 12,200

Carbon dioxide is the reference chemical species because it makes up the majority of GHG's at 65% of global emissions (EPA, 2016); CO_2 makes up 79% of Canadian GHG emissions as of 2016 (ECCC, 2018b) (Figure 1).

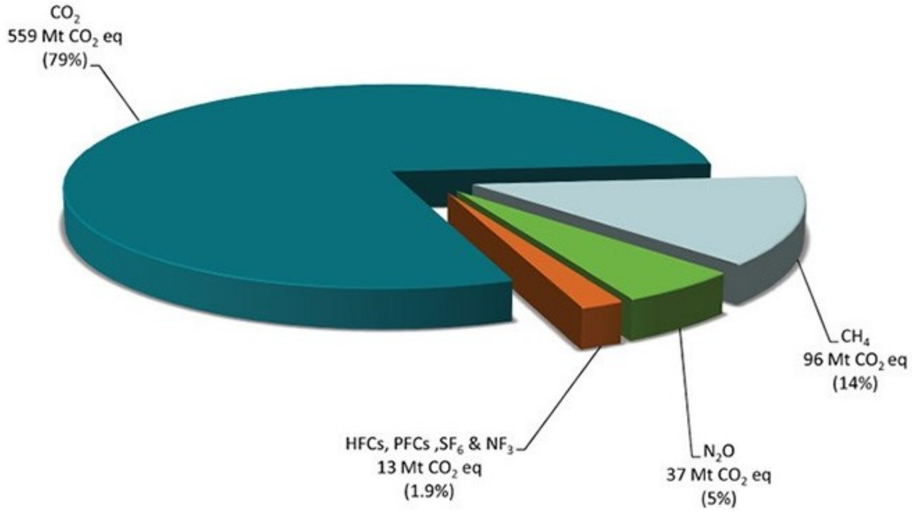


Figure 1. Canada's emissions by GHG, 2016, (ECCC, 2018b)

Reducing GHG emissions can limit climate change risks, but requires several methods and policies, at a variety of scales, if mitigating strategies are to be effective (UNFCCC, 2016a; IPCC, 2014). According to the Intergovernmental Panel on Climate Change (2014):

> Continued emission of greenhouse gases will cause further warming and long-lasting changes in all components of the climate system, increasing the likelihood of severe, pervasive and irreversible impacts for people and ecosystems. Limiting climate change would require substantial and sustained reductions in greenhouse gas emissions which, together with adaptation, can limit climate change risks (IPCC, 2014, p. 8).

In December 2015, the 21st Conference of the Parties[2] (COP21) was held in Paris, France; it led to new global agreements on mitigation, adaptation and financing strategies for climate change action (UNFCCC, 2016c). The urgency to accelerate and increase actions and investments required to limit climate change impacts, was, for the first time, an almost universally unanimous priority that culminated in a historic agreement. There were 195 countries committed to actions and investments towards a low carbon, resilient and sustainable future. The primary aim was to limit global temperature rise to well below 2°C above pre-industrial levels

---

[2] The supreme decision-making body of the UNFCCC (UNFCCC, 2000)

within this century, and to pursue efforts to limit the increase to 1.5°C (UNFCCC, 2016c). COP21 also sought to strengthen the ability of countries to deal with climate change impacts by creating clearer accountability of climate actions, adaptation and recovery strategies, and stronger financial support (UNFCCC, 2016c).

Significant GHG emissions reductions over the next few decades and near zero emissions by 2100 are broadly accepted to be the necessary progressions to avoid warming greater than 2°C above pre-industrial levels (Gao, Gao, & Zhang, 2017; IPCC, 2014). Multiple mitigation pathways will be necessary and the transition will be complex, creating technological, societal, economic, and institutional challenges (PCF, 2016; IPCC, 2014). Evidence suggests that key measures to reduce emissions without compromising development include; reducing the carbon intensity of electricity generation, increasing energy efficiency, and encouraging behavioural changes (IEA, 2017; IPCC, 2014).

Amongst the many human activities that produce GHG emissions and contribute to climate change, fossil fuel-based energy utilization is by far the largest source of emissions, representing 68% of global anthropogenic GHG emissions in 2014 (IEA, 2017). Within the energy sector, mitigation strategies can be targeted further, as the majority of CO_2 emissions are produced by two sectors: electricity and heat generation (42%), and transportation (24%) (IEA, 2017) (Figure 2).

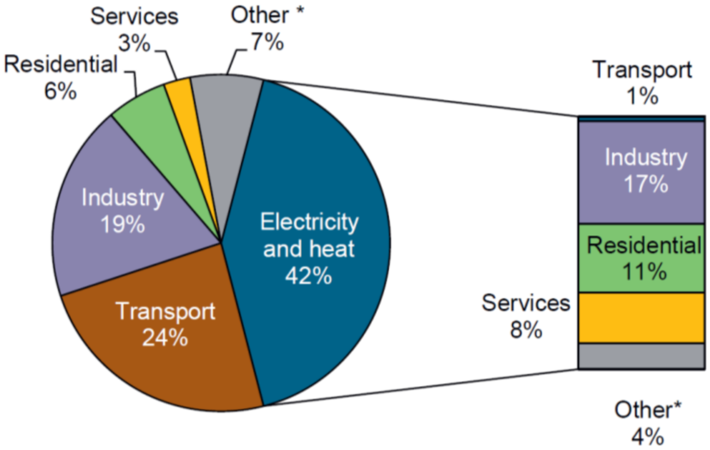


Figure 2. World CO_2 emissions, fossil fuel combustion sector, 2015 (IEA, 2017)

*Other includes agriculture/forestry, fishing, energy industries other than electricity and heat generation, and other emissions not specified elsewhere.

Energy emissions reduction policy has tended to favour supply-side options with investment in renewable energy development over demand-side energy efficiency (IEA, 2014; Lazar & Colburn, 2013). However, the International Energy Agency (IEA) has, and continues to emphasize the importance of energy efficiency investment as the number one priority for achieving a successful transition to a low emissions economy (IEA, 2016). It argues that energy efficiency should be at the core of all energy policy strategies, and is the single best pathway to a low carbon energy system; “there is no realistic, or affordable, energy development strategy that is not led by energy efficiency” (IEA, 2016, p. 3). Despite this, energy efficiency requirements are lacking in 70% of the world’s energy use, and an estimated two-thirds of all energy consumption within buildings globally have no regulations or building codes that must be adhered to (IEA, 2016). Energy efficiency is far from fulfilling its potential.

2.1.1 Canadian Emissions. While Canada contributes less than two percent of global anthropogenic GHG emissions through domestic emissions (World Resources Institute, 2017), Canadians are amongst the highest global GHG emitters on a per capita basis, at 19.4 tonnes of carbon dioxide equivalent (tCO_2e) per capita (ECCC, 2018b). Federal, provincial and territorial governments in Canada recognize the risks that climate change impacts have on communities, the health and well-being of Canadians, the natural environment, and the economy (PCF, 2017; NRTEE, 2011). In 2011, the Canadian National Round Table on the Environment and the Economy (NRTEE) estimated the annual cost of climate change inaction would be in the range of \$21-\$43 billion to the nation's economy by 2050 (NRTEE, 2011). Even today, severe weather patterns have cost Canadians billions of dollars in losses; moreover, these losses often disproportionately affect lower socio-economic segments of society, Indigenous communities, and northern and coastal regions (PCF, 2016; IPCC, 2014).

2.1.2 Nova Scotia Emissions. Like any other province, Nova Scotia (NS) has a role to play in contributing to reducing Canada's national emission levels. It is estimated that in 2016, NS GHG emissions were 15.6 megatonnes CO_2e from all domestic activities, which is more than those from New Brunswick, Prince Edward Island, Newfoundland and Labrador, and all three Territories (ECCC, 2018b). On a per capita basis, with emissions of 17.2 tCO_2e in 2016, NS ranks fourth highest in Canada, exceeded only by Alberta, Saskatchewan and New Brunswick (NEB, 2016)[3]. Ironically, NS is also one of the provinces more particularly susceptible to the effects of climate change, since the majority of the population and much of the infrastructure is located along coastlines, and in vulnerable areas. The infrastructure in NS was not designed to withstand the extreme and more frequent weather patterns now experienced, nor is the Province's fresh water supply immune, as it now faces a greater risk of salt contamination from rising sea levels (Climate Change NS, 2017a).

---

[3] Although NS is fourth highest among Canadian provinces in per capita emissions, it is below the national average, due to Saskatchewan and Alberta, which generate per capita emissions over three times the national average (66.2 and 65.6 tCO_2e) (NEB, 2016).

2.2 Commitments to GHG Emission Reductions

All Parties of the United Nations Framework Convention on Climate Change (UNFCCC) are responsible for submitting annual summary reports of national GHG emissions inventories (Annex 1). In anticipation of COP21, countries proposed their post-2020 climate actions - known as the Intended Nationally Determined Contributions (INDCs) - detailing the level of emissions reductions they are committed to reaching and their plans to achieve them. The COP21 agreement entered into force in November 2016, making the INDCs formal under the agreement, and from then on referred to as Nationally Determined Contributions (NDCs) (UNFCCC, 2016b). The UNFCCC commissioned a synthesis report in 2015, which assessed the cumulative effects of all INDCs received at the time. The report concluded that even if the implementation of INDCs was fulfilled, global emission levels will not fall below the 2°C scenario, let alone the 1.5°C scenario some countries, including Canada, were advocating for (UNFCCC, 2016b). The urgency to set ambitious emission reduction targets and actions was set in place.

The Climate Action Tracker (CAT), an independent science-based assessment process developed by a consortium of three research organizations, tracks and provides up-to-date emission commitments, targets, NDC’s, and actions of individual countries. Despite the recent United States rollback of COP21 commitments, advancements in China and India have resulted in some positive findings since the 2016 CAT report. However, the majority of countries are still not in line with COP21 agreements. The report states, “24 governments have set insufficient targets; of these, 16 governments have implemented policies that will not even result in achievement of their targets. Only seven governments have implemented 1.5°C or 2°C compatible targets and of these, four are not backed up by sufficient policy action” (CAT, 2017b, p. 2). In December 2017, the CAT released a publication identifying ten key sectoral benchmarks that would put the world on track for limiting global temperatures to the more ambitious 1.5°C scenario. This included recent developments and challenges facing each of the ten benchmarks; of the ten, it emphasizes the priority of improving the electricity sector fastest, aiming to be fully decarbonized by 2050 (Kuramochi, 2017). Two other initiatives of note require all new buildings to be fossil fuel-free and net-zero energy by 2020, and increase building renovation rates from less than 1% per annum in 2015 to 5% by 2020 (Kuramochi, 2017).

2.2.1 Electrification. There is a growing body of literature emphasizing that electrification of society is the clearest and most attainable path to significant GHG emission reductions (Jacobsen, et al., 2015; Mahone, et al., 2015; Dennis, 2015; ENE, 2014). Based on available technology (i.e. not relying on future innovation) the path to net zero emissions involves a two-pronged strategy: i) full electrification of society; and ii) developing net-zero emission electricity grids (Jacobsen, et al., 2015; Mahone, et al., 2015; Dennis, 2015; ENE, 2014).

Most technologies that have traditionally used fossil fuels, such as combustion engines for transportation and furnaces or boilers for space heating, now have electrically-based alternatives, enabling fuel switching (CAT, 2016). The concept of fuel switching involves replacing higher carbon content fuels with lower carbon content fuels to reduce GHG emissions (Ghosh, 2016). Some obvious fuel switching alternatives include replacing combustion vehicles with electric vehicles (EV’s), and replacing fossil fuel-based heating systems with HPs for both space and domestic hot water (Jacobson, et al., 2015; Mahone, et al., 2015; Dennis K. , 2015). This kind of fuel switching enables a reduction of the technology’s environmental impact over its lifetime if the electricity supply is sufficiently decarbonized and the usage remains constant after the switch

(Dennis, 2015). Such a transition requires a focus on de-carbonizing the electrical grid if meaningful GHG emission reduction is to be effected.

There are several generation options that could decarbonize the electricity supply. This includes: wind (onshore and offshore), solar, nuclear, hydroelectric, geothermal, tidal energy, and [theoretically] fossil fuel with carbon capture and sequestration (Dennis, Colburn, & Lazar, 2016; CAT, 2016; Jacobson, et al., 2015). The technology mix and path forward to a 'clean' grid is highly debated, but there is general consensus that a path exists, which is economically feasible and technologically possible (IRENA, 2018; Jacobson, et al., 2015; DeCanio & Fremstad, 2011).

2.2.2 Canada Commitments. Canada played an active role at COP21 with its newly elected federal Liberal government in 2015, declaring that 'Canada is back' and committing to reducing GHG emissions at home and assisting developing countries to achieve their objectives abroad (Fitz-Morris & Tunney, 2015). Among other things, Canada ratified its commitment to reducing economy-wide GHG emissions to 30% below 2005 levels by 2030 (UNFCCC, 2015). This is in addition to Canada's Copenhagen pledge of reducing GHG emissions by 17% below 2005 levels by 2020 (Government of Canada, 2010), and Canada's long-term pledge of reducing emissions by 80% below 2005 levels by 2050 (ECCC, 2016).

As a first step towards fulfilling its commitments to such pledges, the First Ministers of Canada, representing the Prime Minister and provincial premiers, released the Vancouver Declaration of Clean Growth on Climate Change in March 2016. From this declaration, the Pan-Canadian Framework on Clean Growth and Climate Change (PCF) was developed in December 2016, the first truly comprehensive climate action plan in Canada (PCF, 2016). Using a mix of regulations and investments, the PCF pledges to: a) phase out fossil fuel subsidies no later than

2025 and coal-generated electricity by 2030; b) ensure a minimum nation-wide carbon price of $10 per tonne of carbon emissions by 2018 and $50 per tonne by 2022; and c) encourage energy efficiency and fuel switching in the built environment, transportation and industrial sectors (UNFCCC, 2017; PCF, 2016).

Despite this policy progress, Canada is at risk of missing its NDCs. Canada has a current rating of 'highly insufficient' by the CAT, the second worst out of six categories, concluding that Canada needs to significantly improve its NDC and proposed level of action (CAT, 2017a). Similarly, a recent report by the National Research Defence Council and the Pembina Institute concluded that even if Canada implements all the policies and climate actions outlined in the PCF, it will still be behind pace of reaching its NDC target of 30% below 2005 emission levels by 2030 (NRDC, 2017).

If Canada is to meet its international and domestic environmental commitments, it clearly needs to improve its level of climate action. The CAT highlights the importance of carbon pricing and fuel phase out, and the establishment of initiatives like the Low Carbon Economy Fund (LCEF) (CAT, 2017a). According to the federal government, the LCEF will contribute $2 billion to support projects with provinces, territories, municipalities, Indigenous organizations, businesses, non-profit and for-profit organizations, towards actions related to reducing Canada's GHG emissions and contribute to clean economic growth (ECCC, 2017b).

A key component of Canada's climate action strategy for reducing emissions is a focus on energy efficiency. According to a recent report, Canada can reduce its energy consumption by 15% by 2035 through aggressive pursuit of efficiency improvements alone (Robins, 2017). The report suggests a focus on lighting, space heating and electronics for residential energy reductions, and lighting, computer and HVAC for commercial reductions. Since Canada, on average nationally, has a relatively low GHG emission intensive electricity system, the most important climate change mitigation measures are those that transition away from the use of hydrocarbons to produce heat (Robins, 2017).

2.2.3 Nova Scotia. NS has set ambitious targets supported by effective policy towards climate action in recent years and the progress has been impressive. Technically, NS is ahead of Canada in achieving GHG emissions reduction targets, it is already 30% below 2005 emission levels and 17% below 1990 levels, which is the most improvement of any province in Canada (Climate Change NS, 2017b). However, it is important to look back and contextualize the last ten years of progress, to appreciate the Province's future direction and obligation to improve further.

In 2007, almost 90% of electricity generated in NS came from fossil fuels, the majority of which was coal at 76% (NSP, 2016b; Adams, Wheeler, & Woolston, 2011). While the dependency on coal for electricity was not unique to NS, the GHG emissions produced from coal-fired electricity generation relative to total emissions was much higher at 50% of total emissions, compared to the Canadian average of only 10% (Abreu, 2013). The opportunity to reduce provincial emissions by focusing on the electricity sector was far greater in NS and the path forward became clear.

In the same year, an aggressive piece of legislation called the *Environmental Goals and Sustainable Prosperity Act* (EGSPA) imposed targets to reduce provincial GHG emissions, promote renewable energy generation, improve air and water quality, and protect ecosystems (Environmental Goals and Sustainable Prosperity Act, 2007). EGSPA laid out the foundation for three key regulations that committed the Province to ambitious emission reductions. Nova Scotia's Climate Change Action Plan (2009) targeted the Province's largest single source of GHG emissions – NSP's thermal-electric electricity generating stations (Environment NS, 2009).

The plan led to NS being the first province to impose hard emissions caps on its electricity sector (Greenhouse Gas Emissions Regulations, 2009). Created in 2009 and enhanced in 2013, the *Greenhouse Gas Emissions Regulations* that was passed pursuant to the province's *Environment Act*, required NSP to phase out all coal combustion and reduce GHG emissions by 25% in 2020 and by 55% by 2030 relative to 2009 emission levels (Greenhouse Gas Emissions Regulations, 2009). Following this in 2010, the Province created the Renewable Electricity Plan and amended the *Renewable Electricity Regulations*, which made the original targets outlined by EGSPA the law, obligating NSP to generate 25% of all electricity in the province from renewable energy sources by 2015 and 40% by 2020 (Adams, et al., 2011; NS DOE, 2010; Renewable Electricity Regulations, 2010). To enhance stakeholder commitment to renewable electricity generation, the Province introduced a community feed-in tariff (COMFIT) program in 2011 that offered a guaranteed price per kWh to community-based power producers. With an initial goal of 100 megawatts (MW) of new renewable generating capacity development, the program was highly successful, approving 220 MW of community-based renewable electricity (mostly wind) between 2011 and 2015 (NS DOE, 2015a). This put the Province on path to meet its 2015 and 2020 obligation of 25% and 40% renewable energy (NS DOE, 2015a).

In addition to COMFIT, a 35-year investment into an infrastructure mega project known as the Maritime Link is underway, involving 170 kilometres of sub-sea transmission cables connecting NS with low emission intensity, renewable hydro electricity from Muskrat Falls in Newfoundland and Labrador (Emera, 2017). The other major renewable energy initiative in NS is in the Bay of Fundy, which experiences the strongest tides in the world, and has attracted multiple levels of investment to develop an in-stream tidal generator and produce electricity (NRCan, 2017g; FORCE, 2016). Some progress has been made, including a successful connection of a 2 MW test turbine to subsea power and data cables that could produce electricity (FORCE, 2016). However, it is uncertain if tidal in-stream conversion technology in the Bay of Fundy will generate sustainable and competitively priced electricity (Daborn, 2016; MacGillivray, Jeffrey, & Wallace, 2015), so its contributions to provincial GHG reductions remains unclear.

2.2.4 Electricity sector Nova Scotia. Since the largest source of emissions in the province is electricity generation (NEB, 2016) and the caps imposed on this sector require a reduction to 4.5 million tCO_2e by 2030 (approximately 55% reduction from 2009 levels) (Greenhouse Gas Emissions Regulations, 2009), it is anticipated that the largest gains in emissions reductions will be achieved in this sector. To ensure emissions cap compliance, NSP recently tabled a plan for the Province’s electricity future that mainly relies on previous investments in renewable energy (mainly COMFIT) to reduce emissions (NS DOE, 2015c). Overall and especially in the near-term, the province intends to meet increases in electricity demand through improvements to demand-side management and efficiency measures, rather than new sources of renewable energy generation (NS DOE, 2015b). In the long term (post-2040), the plan calls for considerable growth in local renewable supplies such as tidal, solar, or sources not yet developed (NS DOE, 2015c).

2.2.5 Demand-side management. Nova Scotia has made considerable improvements to demand-side management of electricity consumption. In 2015, NS created Canada’s first energy efficiency utility for demand-side management – Efficiency Nova Scotia (ENS), which provides financial assistance to homeowners and businesses for energy efficiency upgrades. Nova Scotia Power is required by law to purchase energy efficiency deployment services from ENS when the cost of saving electricity is less than the cost of generating, and this service is funded through customer electricity rates. The Nova Scotia Utility and Review Board (NSUARB) provides regulatory oversight to NSP and ENS, requiring approval on all activities (NSUARB, 2017a). This type of efficiency utility that holds ENS accountable to rate payers and with oversight by a third party (the NSUARB), ensures cost-effectiveness and is recognized as a best practice (Weis, 2012; IEA, 2011). According to ENS, its energy efficiency programs have achieved annual savings of $150 million in energy costs and reduced GHG emissions by 700,000 tCO_2e annually (ENS, 2017a).

To understand the opportunities for reducing GHG emissions further through demand-side management in NS, it is important to identify where energy is being consumed, particularly as the vast majority of the primary energy carriers used are fossil fuel derived (Figure 3).

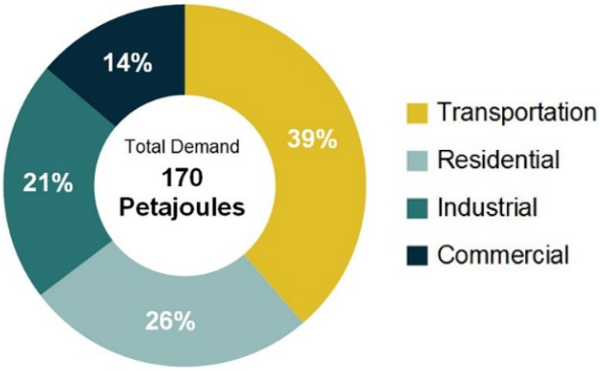


Figure 3. NS end-use demand by sector, 2016 (NEB, 2016)

The transportation sector in NS is the largest sector for energy demand at 39% of the total (NEB, 2016) (Figure 3). Nova Scotia is currently investing $3.7 million towards sustainable transportation and infrastructure (Climate Change NS, 2017c), and the Department of Energy is committed to reducing the sector's GHG emissions and contribute to the Province's reduction targets (NS DOE, 2017). The emergence of electric vehicles (EVs) as an alternative to traditional combustion engine vehicles has been shown to reduce GHG emissions in NS, and the reduction potential will increase as NSP generates more electricity from renewable sources (Hughes, 2016). The province is looking at options to encourage EV adoption for both personal and public transportation, and has committed $100,000 to ENS (NS DOE, 2013).

2.2.6 Residential sector emissions. Second to transportation, the residential sector consumes 26% of total energy demand in NS (NEB, 2016) (Figure 3). This sector provides much greater opportunity to reduce overall provincial level emissions compared to the rest of Canada because it represents a greater portion of its total emissions. That is, residential sector emissions represent 14% of total emissions in Canada compared to 26% in NS (NEB, 2016). This is largely due to industrial sector emissions making up 51% of Canada-wide emissions but only 21% of NS emissions (NEB, 2016); which is largely attributed to the closing of several coal mines and pulp and paper mills in the early 2000's. Much of residential emissions come from space heating at 66%, which is similar to the Canadian average and not necessarily surprising considering the country's relatively cold climate and widespread access to traditionally inexpensive fossil fuels (NRCan, 2015d). This is followed by water heating at 17%, appliances at 13.6%, lighting at 3.3% and space cooling at 0.3% (NRCan, 2015d) (Figure 3).

2.2.7 Space heating energy efficiency. At two-thirds of all residential GHG emissions, space heating efficiency is an obvious target for further emissions reductions. Not surprisingly, ENS offers a variety of programs aimed at improving space-heating efficiency; the two most prominent are the Home Energy Assessment (HEA) and Green Heat (GH) programs. Both provide financial incentives, including rebates and low-cost financing, to encourage homeowners to improve efficiency by replacing or improving existing low-efficiency, electricity-based heating system or by reducing heat loss through building envelopes (ENS, 2016). Other programs offered by ENS provide participants with direct installation of energy-efficient products such as LED lights and low-flow showerheads free of charge and, not surprisingly, get more participation than HEA and GH. However, because of the efficiency gains from space heating, HEA and GH achieved reductions of approximately 6400 and 6000 kWh annually per participant respectively, compared to 200 and 500 kWh per participant saved in free-of-charge ENS services (ENS, 2016).

Opportunities to increase space heating efficiency and reduce related GHG emissions in NS will likely remain at the forefront of energy efficiency policy in the foreseeable future. As previously implied, ENS heating incentive programs are currently only offered to homes that heat with electricity (Climate Change NS, 2017b; NSP, 2015; NRCan, 2015d). However, the majority of homes heat with HHO (see §2.3). Immediately prior to the conclusion of this study (June 2017), the Federal government announced that it would provide NS with $56.3 million (over five years) via the $2 billion Low Carbon Economy Fund (LCEF) (ENS, 2017b); it is expected that the funds will support ENS programs to include homes heated with HHO (Berman, 2017; ENS, 2017b).

2.3 The Nova Scotia Residential Heating Sector

The primary source of heating for residential homes in NS has differed from the rest of Canada, primarily due to the lack of availability of affordable natural gas. Natural gas is currently the most common fuel source for residential heating in Canada (~50%) (NRCan, 2015b). However, Nova Scotian residents have little access to natural gas, with just over 2% of homes using it as the primary heating source in 2015; this statistic has barely changed in the past 15 years (NRCan, 2015e). Instead, Nova Scotians have relied on HHO as the primary fuel source for home heating for much of the past century, with electric baseboard heating as the second most common source (NRCan, 2015e; NSP, 2015)

The uncertainty surrounding the current snapshot of residential heating systems - by fuel type - in NS is due to inconsistency in available data (Figure 4). For example, NRCan's Canada Energy Use Data Handbook (CEUDH) suggests over 50% of homes have HHO as the primary source of heating (NRCan, 2015e), whereas results from a 2015 NSP customer survey indicate 40% of homes as having HHO as the primary source of heating (NSP, 2015) (Figure 4).

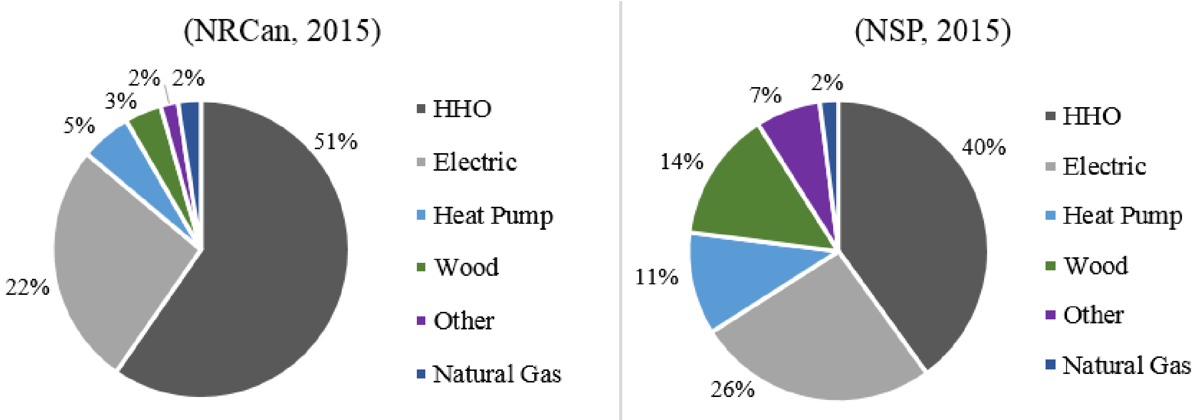


Figure 4. NS residential space heating sources by primary fuel source

According to the NS Climate Change website, it is estimated that 100,000 households in NS now heat their homes with a HP; at least 80,000 for primary heating (Climate Change NS, 2017b). Using the 2016 Canadian census for total number of homes in NS (StatsCan, 2016), this equates to HPs in nearly 25% of homes in NS and 20% for primary heating (Climate Change NS, 2017b). If the NS Climate Change website is accurate, this indicates a potential shift in heating fuel sources towards HPs; however, it is still unclear which fuel source(s) these HP adopters are shifting away from. Despite this uncertainty, a review of past and current heating market trends and options in NS can provide clearer direction for the future.

2.3.1 Natural gas. Although natural gas is an affordable and relatively cleaner option for home heating in most Canadian regions (NRCan, 2015a), NS faces supply constraints (Atlantica Centre for Energy, 2015), resulting in the fuel being less affordable compared to other North American markets, such as Ontario (Ontario Energy Board, 2018; Heritage Gas, 2018). Natural gas is the primary heating source in only 2% of residential NS homes (NRCan, 2015e). For households that have access to it, according to ENS, natural gas is one of the most affordable and cleanest forms of home heating in the province in terms of GHG emissions (Figure 5). However, there is likely no more room for improvements to natural gas combustion technology, which has already achieved 98.5% combustion efficiency (USDOE, 2017a). Unless new technologies such as carbon capture and storage can be coupled with natural gas in the residential sector, the fuel source has reached its peak in terms of limiting emissions in residential heating. In the long run, if deep emissions reductions are to be achieved in the residential heating sector, a move away from natural gas is likely necessary:

> The rationale for reducing the role of natural gas in households, businesses, and industries is that, if the U.S. commits to about an 80% or higher CO_2 emissions reduction by 2050, it would not only have to reduce natural gas usage for electricity production but also for water and space heating. Unless something dramatic occurs in transportation, little room exists for reducing emissions in other sectors. This means that natural gas consumption would have to drastically decline in the future to meet the stringent targets. (Costello, 2017, p. 18)

2.3.2 Propane. Propane has not captured significant market share for primary residential home heating in Canada and NS with estimates at less than one percent (NRCan, 2015e; NSP, 2015). Considering the relatively small market share, the future of this fuel as a primary heating source in NS seems unlikely. Moreover, it has similar emission reduction limitation noted for natural gas.

2.3.3 Wood / biomass. Wood or biomass for residential heating is more common in NS than the rest of Canada, with approximately 4% of homes using it for primary heating (Figure 4) compared to 1.9% in the rest of the country (NRCan, 2015b). Wood is abundant in NS; with a high-efficient stove or fireplace, it can be the cheapest form of heating (Figure 5). The environmental impacts of using wood for heating fuel is open to debate. The NS government considers wood to be a carbon neutral fuel source; therefore, ENS offers incentives to encourage wood or wood-pellet heating equipment installations (ENS, 2017c). The theory is carbon emissions are re-captured by the re-growing forest over time. Research has shown that the wood fuel carbon cycle is a complex process and the emissions implications vary considerably, depending on: the combustion technology; the energy source being replaced; the biophysical and forest management traits of the wood supply; and the distance between harvest site and end-users (Helin, Sokka, Soimakallio, Pingoud, & Pajula, 2013; Manomet Center for Conservation Sciences, 2010; Raymer, 2006).

2.3.4 Solar Thermal. Solar thermal space heating is a form of active solar technology that uses strategically placed collectors on the home to capture the sun's heat and transfer it inside (NRCan, 2017f). Solar thermal is a clean renewable technology with incentives available to residential homes in NS. If appropriately sized and installed, solar thermal heating can increase temperatures in the home by 10 to 15°C, but the main objective is to supplement primary home heating (ENS, 2017e). Although solar thermal heating has been gaining ground in many countries, its primary application in NS is for domestic water heating (Wang & Ge, 2016).

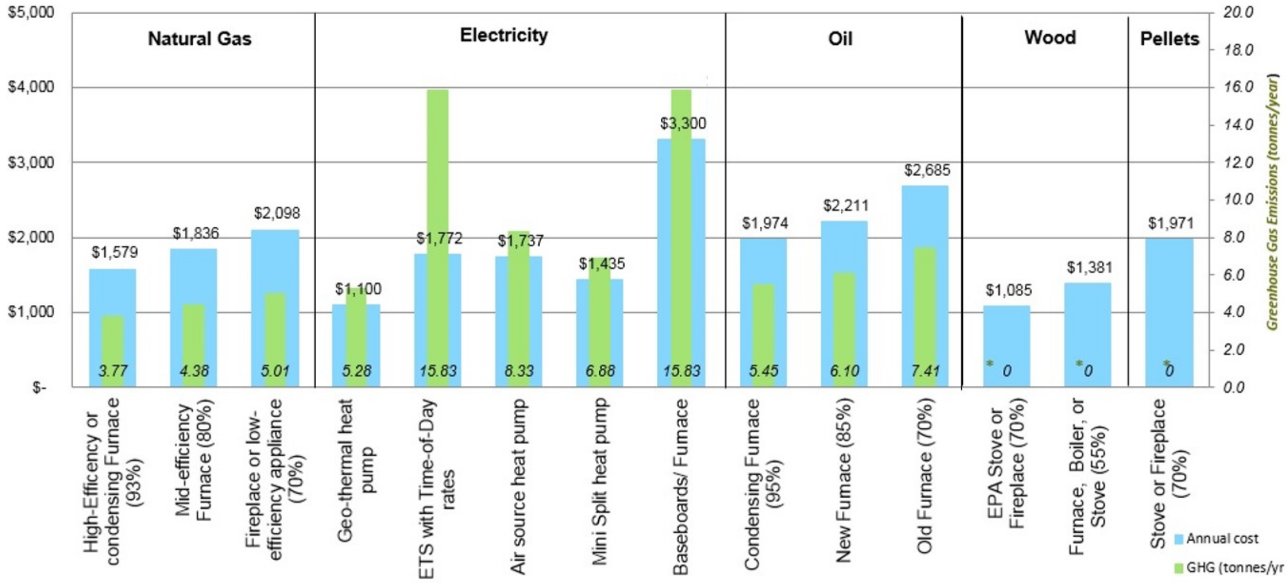


Figure 5. Typical NS space heating costs and emissions, average single-family residence (1700 square feet, 4 people). (ENS, 2017d)

2.3.5 Home heating oil. As noted, NS has traditionally relied heavily on HHO for residential space heating needs, with estimates as high as 50% of all homes using it for primary home heating (NRCan, 2015e) (Figure 4). Home heating oil is a refined petroleum product; it must be transformed from crude oil in a refinery just like automotive gasoline (NRCan, 2015f). The petroleum industry produces several grades of HHO, but the most common is referred to as “Light fuel oil No 2” or “furnace oil,” and it must meet government and industry standards for density, viscosity and heat content (NRCan, 2012). There are no petroleum refineries in NS since the shutdown of the Imperial Oil refinery in Dartmouth in the beginning of 2014 (NRCan, 2015f; Taylor, 2014). Instead, NS relies on a variety of sources to import HHO including from the United States and Europe (Taylor, 2014). This lack of domestic supply of HHO can lead to availability issues, especially during the high demand winter heating season. As recently as January 2014, NS faced availability issues when a series of record-setting cold temperatures and bad weather led to a HHO shortage in parts of NS (Budale, 2014).

Affordability issues are also a challenge for Nova Scotians, as HHO is not a regulated commodity (Taylor, 2014) and consequently consumers are exposed to global volatile price fluctuations. For example, in Halifax, NS, the January price per litre of heating oil went from 86 cents in 2010, up to 125 cents in 2014, back down to 86 cents in 2016, and as of January 2018 is at 105 cents (StatsCan, 2018). Acceptability issues for home heating are generally measured in terms of home comfort, ease-of-use, and environmental impacts. Home heating oil is an acceptable form of heating in terms of home comfort and ease-of-use; however, its environmental acceptability – in terms of GHG emissions (Hughes, 2012) – is not as clear relative to HPs due to the carbon intensive electricity generating sources in NS (NSP, 2017a). There are other environmental acceptability concerns with HHO beyond GHG emissions, such as leaks from storage tanks or spills during transportation that can lead to soil contamination with costly remediation or health hazards (Environment NS, 2017).

2.3.5.1 HHO distribution systems & efficiency. Within the home, HHO systems consist of a heating unit and a distribution system. The most common oil heating units in Canada are furnace forced-air systems, which can provide heat quickly, distribute and ventilate air throughout the home using ducts, motors and registers, and can also be used to provide central air-conditioning if additional equipment is added (NRCan, 2012). Hydronic boiler systems are also common, especially in older homes. Hydronic boiler systems circulate heated water through pipes to radiators located throughout the home, which diffuses the heat, and then the water returns to the boiler for re-heating (NRCan, 2012).

All furnaces, boilers and other HHO combustion equipment sold in Canada face minimum efficiency requirements, measured by the annual fuel utilization efficiency (AFUE). The AFUE is the ratio of annual heat output of the HHO system compared to the annual fuel input consumed by the system, and does not include the electric energy required to operate controls, fans or pumps (USDOE, 2017a; Kelechava, 2017). Since 1998, all oil furnaces must achieve at least 78% AFUE and as of 2010, oil boilers must meet a minimum efficiency of 84% AFUE (NRCan, 2012). Today’s modern oil furnaces can achieve efficiencies up to 98.5% AFUE (USDOE, 2017a).

Home heating oil system performance can vary significantly for the individual household. In addition to the home’s insulation and layout, proper installation and sizing, operation, and maintenance of the HHO system will result in drastically different heating efficiencies. Despite the potential of 98.5% AFUE of modern furnaces, there are many older systems in use today. Typical HHO heating system efficiencies in Canada range from 60 to 90%, with an average of

78% (NRCan, 2012). In comparison, in NS, a recent analysis and comparison of heating system options suggests a typical AFUE range for oil furnaces of between 70% and 95% (ENS, 2017d)

2.3.6 Electricity. Heating with electricity is common in NS with estimates of approximately 25% of all homes (Figure 4). Approximately 95% of Nova Scotians get their electricity from NSP, and NSP generates its electricity primarily in NS (NSP, 2017e). Currently, NSP imports approximately 5% of the electricity it sells to customers each year from New Brunswick, but levels of purchased electricity will likely increase as new access to hydro electricity sourced from Muskrat Falls in Labrador becomes available via the Maritime Link (NSP, 2017d). However, although NSP generates its electricity locally in NS and has access to sources in neighbouring provinces, the notion of energy security is misleading. The majority of electricity generated today (and even by 2020) will still come from imported coal, natural gas and oil combustion (NSP, 2017a), and is therefore still subject to volatile global supply and price fluctuations. Like the market for HHO for residential heating, as the price of coal, natural gas and oil increases, NSP will incur more costs to meet the same levels of demand, thereby passing those costs onto customers.

The vulnerability to price fluctuations for imported fossil fuels is less severe for NSP generated electricity than is the residential market for HHO because the generation ‘fuel’ supply is becoming increasingly diverse. By 2020, NSP is predicted to generate 57% of its electricity from local renewable sources, including 20% from NS hydro and tidal stations, and 18% from NS wind farms (NSP, 2017a). The benefits of this are a more reliable, domestically produced, cleaner supply of electricity for Nova Scotians. As NS achieves a greater percentage of renewable electricity generation, the path to lower emissions for the residential heating sector becomes more clear.

2.3.6.1 Electric heating distribution systems & efficiency. Within the home, electric heating systems come in a variety of forms such as a central heating unit coupled to a distribution system, or strategically placed space heating units with no distribution network. Except for HPs, which will be discussed further in the next section, all other forms of electric heating systems use electrical resistance to generate heat. Resistance heating works on the principle that an electric current passing through a resistor will convert that electric energy into heat energy, at near 100% efficiency (USDOE, 2018a). Therefore, 1 kWh of electricity input will yield nearly 1 kWh of heat output. The heat is then distributed throughout the home by central forced-air furnaces or hydronic systems, or simply through natural air convection. Room heaters consist of electric baseboard heaters, electric wall heaters, and electric space heaters. Electric radiant heating uses technology similar to room heaters but instead are installed in-floor or in-walls; distribution relies on radiant heat transfer from the hot surface of the heater to people and objects in the room, via infrared radiation (USDOE, 2018b). Radiant in-floor heating also uses natural convection as air warmed by the floor rises, and is often more efficient than electric baseboard and central forced air systems (USDOE, 2018b).

2.3.6.2 Electric Thermal Storage (ETS). Residential ETS systems use electrical resistance elements to heat ceramic bricks[4] to a desired temperature in the storage core of the system, and then the heat can be drawn from and used at a later time (Arteconi, Hewitt, & Polonari, 2013; Arteconi, Hewitt, & Polonari, 2012). They are designed for use with time-of-day electricity rate applications (ENS, 2018a; Arteconi, et al., 2012). That is, many electric utilities structure billing rates in tiers, with more expensive rates being paid during on-peak hours (e.g. dinner time) when the cost of generating electricity is highest, and lower billing rates during off-peak hours (in the

---

[4] There are other storage materials used in ETS systems; however, ceramic bricks are the most prevalent in residential ETS systems (Arteconi, et al., 2012).

middle of the night) when the cost of generating is lowest (Arteconi, et al., 2012). Nova Scotia Power provides time-of-day billing to customers that have the capacity to store heat, so they can take advantage of using electricity to produce and store heat during off-peak times, and then use that heat throughout the day (NSP, 2018). Due to the tiered billing structure, ETS systems can lower heating costs for the homeowner and pair well with many electric heating technologies, including all forms of electric resistance heating and HPs (USDOE, 2018a). In a 2011 case study comparing the savings of typical electrically heated homes in NS, it was shown that an ETS system can save 41-48% in annual heating costs compared to a baseboard system (Syed, 2011).

2.4 Heat Pumps

Heat pumps absorb natural heat from the outside air or ground and distribute it throughout the home in winter, and can also operate in reverse to remove heat and humidity from the home in summer, thus, providing a year-round heating and air conditioning solution (ENS, 2017f; NRCan, 2017a). There are two main types of heat pumps: ground-source (or geothermal) and air-source. Ground-source heat pumps (GSHP) work similarly to air-source; however, they benefit from using the relatively constant temperature of the soil a few feet below the earth's surface as the exchange medium rather than the outside air temperature (USDOE, 2017b).

2.4.1 The potential for heat pumps. Similar to Nova Scotia, a significant proportion of homes and businesses in the Northeast United States (i.e. New England, New York, New Jersey, and Pennsylvania) use HHO and/or electric baseboard for heating (Matley, 2013). A recent study by the Rocky Mountain Institute found that displacing HHO with HPs in the Northeast United States would save a significant amount of money on regional heating costs (Matley, 2013). More specifically, the study suggested that:

> Over the long term, heat pumps have reduced exposure to volatile fossil fuel prices (particularly natural gas), and can be paired with renewable electricity

> generation. Entirely replacing oil heating with heat pumps can save the region \$5.5-6.0 billion in fuel cost annually. Paired with a renewable grid, heat pumps can also put the region on track to meet the 80% greenhouse gas reduction target that the U.N. Intergovernmental Panel on Climate Change (IPCC) has declared necessary to avoid the most dramatic impacts of climate change (Matley, 2013, p. 3).

2.4.2 Heat Pump Operation Efficiency Advantage. Heat pumps have been around for decades and simply extract heat from one place and transfer it to another, the same way a refrigerator or air conditioner operates (NRCan, 2017a). Instead of using electrical resistance to produce heat, HPs use electricity to perform a mechanical operation that extracts heat from the outdoor environment and transfers it into the home. Even in Canadian winters this can be an effective and efficient way to heat as, for example, air at -18°C contains 85% of the heat energy it contains at 21°C relative to 0 degrees Kelvin (ENS, 2017f). The heat is transferred through a refrigerant, which has a very low boiling point and absorbs heat more rapidly than water (NRCan, 2017h). The refrigerant circulates between two heat exchanger coils located indoors and outdoors and through a cycle of evaporation and condensation (NRCan, 2017h). In heating mode, the refrigerant is evaporated at low pressure outdoors to absorb heat from its surroundings, and then on its way indoors to the other exchange coil, it is compressed at high pressure to release the heat absorbed earlier in the cycle indoors (Figure 6) (NRCan, 2017h; Chau, Chou, & Yang, 2010; Guoyuan, Qinhu, & Yi, 2003). In the summer, HPs operate in reverse to provide interior cooling. Figure 6 illustrates how air-source ducted (central) and ductless (mini-split) HP systems can be configured, but there are also air-to-water heat transfer systems which also have benefits. Homeowners have several factors to consider when selecting the best type of HP for their home, and will be discussed further in the next section.

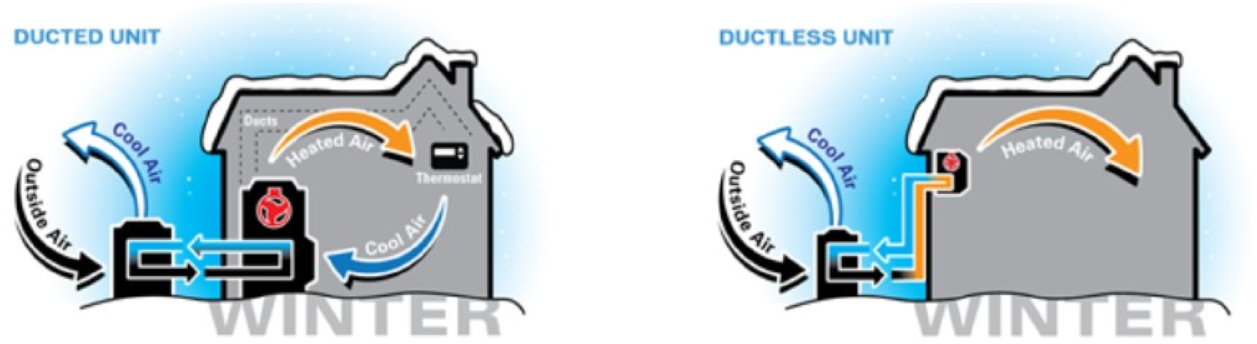


Figure 6. Heat pump operation in heating mode, ducted vs ductless system **(NSP, 2017f)**

A main reason for HPs heating efficiency advantage is attributed to its variable capacity and use of instantaneous power at different speeds (NEEP, 2017a; USDOE, 2017b; NRCan, 2017a). Heat pumps can draw more power and ramp up capacity over a wide range of outdoor temperatures, and are extremely efficient at only part load (NEEP, 2017a). Heat pumps will work much harder to supply heat to the interior of a home when the outside air temperature is - 15°C compared to 15°C, and the heat is delivered intermittently with cut-out periods throughout the day.

Since almost all models of HPs use electricity to perform the mechanical operation of exchanging heat, the GHG emissions produced per unit of interior space heating delivered depend on the efficiency performance of the system and the generation source of electricity. System efficiency is generally measured by the coefficient of performance (COP), which is determined by dividing the thermal energy output by the electrical energy input required to run the HP (NRCan, 2017a). A higher COP means higher efficiency. If operating at a COP of 3.0, this means that 3.0 kWh of heat will be transferred from 1 kWh of electricity.

Heat pumps are often add-on heating sources that supplement the existing heating source, but can also be installed as full systems with their own supplementary heating systems in the form of electric-resistance heating (NRCan, 2017a). As outside air temperatures drop below 0°C, the performance of HPs drastically reduces. Although the technology has demonstrated continuous improvement in this area, even in temperatures as low as -15°C (NEEP, 2017a; Safa., 2015), the HP performance will eventually decline to the point that supplemental heating is required to maintain home comfort. However, NS seldom reaches these low temperatures: the average temperature in January (the coldest month of the year) from 1981-2010, from three weather stations across the province (Yarmouth, Halifax, Sydney), is - 4.17°C (Environment Canada, 2017).

The COP of HPs have improved significantly in recent years. According to NRCan, the typical COP for HPs is 3.3 at 10°C and 2.3 at -8.3°C (NRCan, 2017a; NRCan, 2004), but this performance indicator has not changed since its 2004 report. In recent years, the Northeast Energy Efficiency Partnerships (NEEP) have facilitated a working group to better characterize HP performance in colder temperatures and at high and low capacities. In recent reports from this organization, average COP values for more modern HPs is notably higher than NRCan's performance indicator of 3.3 at 10°C (Table 2). Remarkably, even at - 15°C and at maximum capacity, the HP is still operating with a COP of 2.09 (Table 2). That is nearly 2.1 kWh of heat transferred to the indoor environment for every 1 kWh of electricity consumed.

Table 2. Average Cold-Climate Heat Pump COP (NEEP, 2017b)

Air Temperature	Average HP COP	
	Min. Capacity	Max. Capacity
8.33°C	4.56	3.42
- 8.33°C	3.02	2.4
- 15°C	2.62	2.09

2.4.3 Equipment Options. Although this study does not distinguish between air-source heat pumps for modelling purposes, HPs come in a variety of options that should be carefully considered before installation. The size of the home and how much space needs heating will determine how many and what sizes of units are required, and other factors such as house shape, number of floors, existing ventilation, and aesthetic preferences will influence appropriate type, and last but not least – budget (Henman, 2014). In a home heating retrofit situation, the existing heating distribution system will be an important factor in HP system choice. For example, if the current system has a hydronic (hot water) distribution system, then an air-to-water heat pump would likely make the most sense, since it can take advantage of the existing in-home heat distribution system. Likewise, if the home has a ducted system, an air-to-air central heat pump could work in conjunction with the existing ductwork. Ductless (or mini-split) heat pumps appear to be the most common HP in NS (ENS, 2017f; Henman, 2014) and in the Northeast Unites States (NEEP, 2017a). In a recent program run by ENS to incentivize HP adoption in the province, over 90% of participants chose the ductless option compared to the central ducted system (ENS, 2016). Importantly though, this is not necessarily representative of province-wide HP utilization, because the program was only available to electrically heated homes which would not likely have had ductwork systems in place.

Ductless HPs generally outperform ducted systems because there are no energy losses associated with blowing air through a potentially leaking and uninsulated ductwork system, which can account for as much as 30% of energy consumption (USDOE, 2017b). In addition, a 2015 report suggested that a large majority of centrally ducted HPs just met or barely exceeded the minimum efficiency requirements; whereas, the ductless market far exceeded the minimum requirements (NYSERDA, 2015)

2.4.4 Heat pump sizing. To estimate a home's heating and cooling needs, a professional contractor should calculate the size of the equipment by using recognized methods, such as the Air Conditioning Contractors of America (ACCA) Manual J, or the Standards Council of Canada

(CSA) F280-M90, "Determining the Required Capacity of Residential Space Heating and Cooling Appliances" to recommend the appropriate HP solution (NRCan, 2017a). Each home is unique, both in the physical properties that make up the space and in occupant behaviour of controlling that space. Although modern HPs can provide most of the heating requirement especially in milder cold climates such as NS, sizing a HP to meet 100% of the heating load is not generally recommended for efficiency or economic purposes. Since HPs do not operate nearly as efficiently at low temperatures, it does not necessarily make sense to meet all heating needs with a HP. As a rule-of-thumb, HPs should be sized to meet 80 to 90% of the annual heating load (NRCan, 2017a; NRCan, 2004).

The more accurate way to determine heating load of a building is to use heating degree-days (HDD), the number of degrees Celsius on a given day that the average temperature is below 18°C (NRCan, 2017c). For example, if the average temperature on a given day is 10°C, then that day has 8 HDD; on a day with an average temperature of 20°C, that day has zero HDD because any temperatures equal to or greater than 18 °C attributes zero HDD. Halifax experienced an average of 4199 HDD annually from 1981 to 2010 (NRCan, 2017d). The majority of this (~93%) is experienced during the heating season from October to May, and with the coldest month (January) containing the most HDD, at 16.3% of the total (NRCan, 2017d).

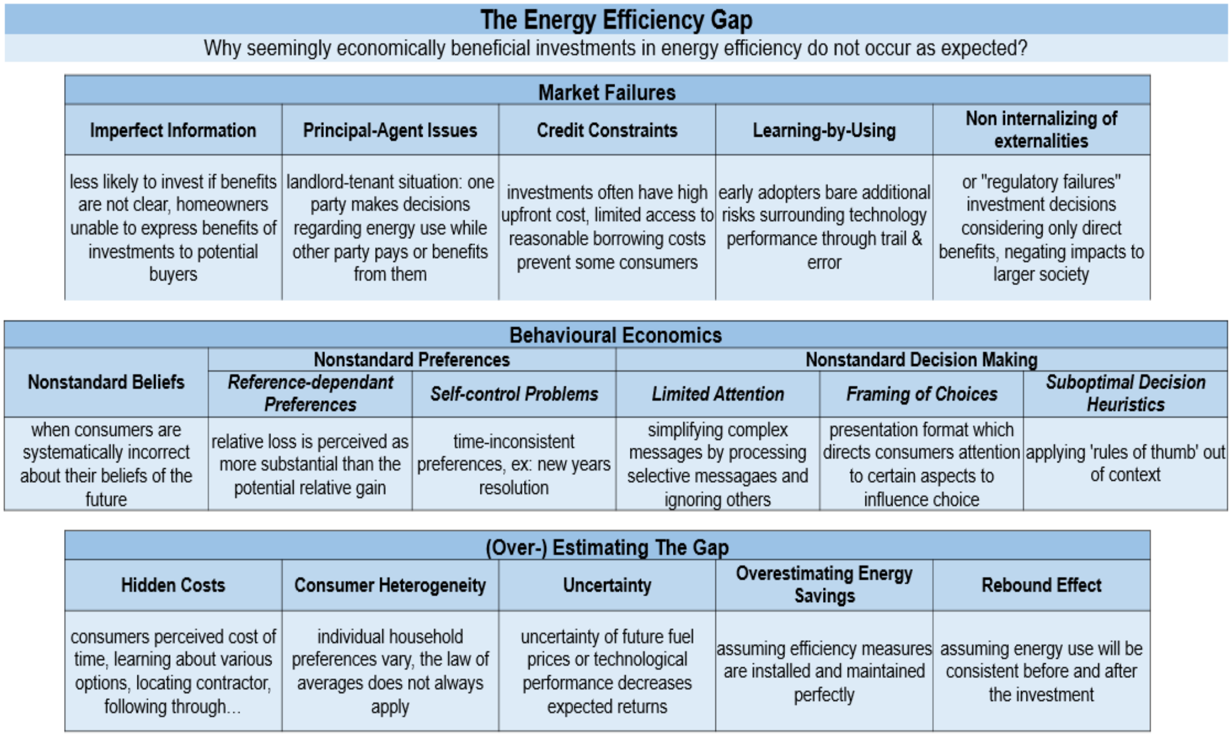
2.4.5 HP installation and equipment costs. Installation costs can vary significantly, as the scope of work fluctuates on a per household basis, depending on the level of modifications to the household (Henman, 2014). Labour costs can also vary by region and application (NEEP, 2017a); however, typically in a North American market, total installation costs of a typical single-zone mini-split HP are $3500 - $4000 (NEEP, 2014) and $4000 per unit (Matley, 2013).

The NEEP 2017 follow-up report on cold-climate HPs provides more comprehensive research on current installation costs. After adjusting to Canadian dollars during the time frame in which the reports were published, estimated costs are $2575 to $3090 (or $732-$878 per kW) (NEEP, 2017a). In any event, it is clear that prices have dropped and are becoming more steady; this cost trend is predicted to continue (NEEP, 2017a).

2.5 Investment in HPs and the Energy Efficiency Gap

The total cost of operating a HP is not limited to the equipment, installation, and fuel costs to run it; homeowners must also budget for borrowing and maintenance costs, and account for non-financial barriers. Non-financial barriers often include hidden costs such as the perceived cost of time to learn about various HP options and locate a suitable contractor; such costs vary considerably from one individual to another (Giraudet & Houde, 2015; Michelsen & Madlener, 2015; Clinch & Healy, 1999). Other non-financial barriers include uncertainty surrounding equipment performance linked to installation challenges or operational deficiencies (Gillingham & Palmer, 2014; Anderson & Newell, 2004; Hassett & Metcalf, 1993). Often such barriers are overlooked in cost-benefit analyses of HP investments, resulting in overstated expectations of net overall savings (Giraudet & Houde, 2015; Michelsen & Madlener, 2015; Clinch & Healy, 1999).

Overstated savings have consistently been linked to lower than expected investment in HPs and energy efficiency in general (Gillingham & Palmer, 2014), a phenomenon known as the energy efficiency gap (*the Gap*). *Gap* related research attempts to explain why seemingly economically beneficial investments in energy efficiency do not occur as expected (Allcott, et al. 2014; Gillingham & Palmer, 2014; Jaffe & Stavins, 1994). There are several factors in the literature that potentially contribute to *the Gap* in addition to overstated expected savings (Palmer & Walls, 2017; Gerarden, Newell, Stavins, & Stowe, 2015). Economists generally recognize traditional market failures as reasons for low investment in energy efficiency, such as imperfect information, principal-agent issues, credit constraints, learning-by-using, regulatory failures, and non-internalizing of externalities (Galarraga, Abadie, & Kallbekken, 2016; Gillingham & Palmer, 2014; Clinch & Healy, 2000; Gerarden et al., 2015) (Figure 7). More recently, economists have proposed a systematic bias in consumer decision-making resulting from behavioural anomalies and behavioural failures that influence investment in energy efficiency (Palmer & Walls, 2017; Alcott et al., 2014; Titenberg, 2009; DellaVigna, 2009) (Figure 7). Overall, under-investment in seemingly economically beneficial energy efficiency measures are typically explained by each of the categories of economics research: market failures, behavioural effects, and over-estimating of savings (Palmer & Walls, 2017; Gerarden et al., 2015; Gillingham & Palmer, 2014; Metcalf & Hassett, 1999; Smith & Moore, 2010) (Figure 7).



The Energy Efficiency Gap

Why seemingly economically beneficial investments in energy efficiency do not occur as expected?

Market Failures

Imperfect Information	Principal-Agent Issues	Credit Constraints	Learning-by-Using	Non internalizing of externalities
less likely to invest if benefits are not clear, homeowners unable to express benefits of investments to potential buyers	landlord-tenant situation: one party makes decisions regarding energy use while other party pays or benefits from them	investments often have high upfront cost, limited access to reasonable borrowing costs prevent some consumers	early adopters bare additional risks surrounding technology performance through trail & error	or "regulatory failures" investment decisions considering only direct benefits, negating impacts to larger society

Behavioural Economics

Nonstandard Beliefs	Nonstandard Preferences		Nonstandard Decision Making		
	Reference-dependant Preferences	*Self-control Problems*	*Limited Attention*	*Framing of Choices*	*Suboptimal Decision Heuristics*
when consumers are systematically incorrect about their beliefs of the future	relative loss is perceived as more substantial than the potential relative gain	time-inconsistent preferences, ex: new years resolution	simplifying complex messages by processing selective messagaes and ignoring others	presentation format which directs consumers attention to certain aspects to influence choice	applying 'rules of thumb' out of context

(Over-) Estimating The Gap

Hidden Costs	Consumer Heterogeneity	Uncertainty	Overestimating Energy Savings	Rebound Effect
consumers perceived cost of time, learning about various options, locating contractor, following through...	individual household preferences vary, the law of averages does not always apply	uncertainty of future fuel prices or technological performance decreases expected returns	assuming efficiency measures are installed and maintained perfectly	assuming energy use will be consistent before and after the investment

Figure 7. Summary of the energy efficiency gap (Palmer & Walls, 2017; Galarraga et al, 2016; Gerarden et al, 2015; Giraudet & Houde, 2015; Michelsen & Madlener, 2015; Gillingham & Palmer, 2014; Allcott et al., 2014; Smith & Moore, 2010; Tietenberg, 2009; DellaVigna, 2009; Anderson & Newell, 2004; Clinch & Healy, 1999; Jaffe & Stavins, 1994; Hassett & Metcalf, 1993)

It is important to include all the costs associated with *the Gap* (Figure 7) to truly capture the total costs of the HP investment to the individual homeowner and to not overstate the potential savings. However, quantifying such costs is not an easy task and is highly debated (Gillingham & Palmer, 2014; Smith & Moore, 2010; Metcalf & Hassett, 1999). Several studies attempt to factor in these costs by manipulating the discount rate applied in the financial index used to rank the investment (Schleich, Gassmann, Faure, & Meissner, 2016; Newell & Siikamaki, 2015). A discount rate accounts for the time value of money, because most human behavior indicates that money in the present is worth more than an equal amount in the future. That is, the dollar in the future is not worth the same amount today because of the potential earnings that could have been made during the intervening time and because of inflation (Schleich et al, 2016; Newell & Siikamaki, 2015; DEFRA, 2010).

Individual discount rates in energy efficiency decisions are highly variable depending on the homeowner’s situation (Schleich et al, 2016; Newell & Siikamaki, 2015). Evidence from a US homeowners survey on preferences for energy efficiency and cash flows over time, finds considerable heterogeneity in individual discount rate, with systematically higher rates found in individuals with less education, low income, poor credit, and larger houses (Broin, Mata, & Nassen, 2015). In addition, individual time preferences influence willingness to invest in energy efficiency (Schleich et al, 2016; Broin, et al., 2015). These findings highlight the importance of accounting for varying discount rate, to fully capture the total investment costs. In a thorough review of studies on discount rates, four observations emerge (DEFRA, 2010, p. 15):

- There is a wide range of observed discount rates, from 2% to 300% (for all energy efficiency studies, 2% to 36% for space heating)
- Most of the observed discount rates are considerably higher than market interest rates;
- Rates differ significantly both between and within product categories; and
- Discount rates are lower when saving energy is the primary purpose of the investment. This is consistent with what one would expect given the ‘isolation effect’ – attention is likely to be focused on those energy savings and so the discount rate for that energy is generally lower

A summary of discount rates applied in academic studies relating to space heating is summarized in Table 3.

Table 3. Ranges of Discount Rates Applied in the Literature for Space Heating in the Residential Sector

Authors	Year	Country	Estimated Discount Rate
Lin et al.	1976	USA	7-31%
Goett	1978	USA	36%
Dubin	1982	USA	2-10%
Goett and McFadden	1982	USA	6.5-16%
Goett	1983	USA	4.40%
Berkovec et al.	1983	USA	25%
Jaccard and Dennis	2006	Canada	9%
Giraudet & Houde	2015	USA	15-35%

Chapter 3: Study Design, Input Assumptions and Analytical Criteria

The primary objectives of this research were to quantify the GHG emission impacts of displacing HHO with HPs for residential home heating in a province that still generates its electricity from carbon intensive sources. In addition, the operating cost impacts and expected net savings to the individual homeowner were examined, to assess whether displacing HHO with HPs makes sense from a private investment standpoint. The specific goals were to quantify:

1. The net annual GHG emissions impact if all residential homes space heating with HHO in 2017 were converted instantaneously to an electric air-source HP in NS.
2. The net annual GHG emissions and operating cost impacts for individual residential homes in NS, who displace HHO with HPs for space heating in 2017.
3. The energy consumption, operating cost and emission impacts over the next 25 years, for individual residential homes in NS, who displace HHO with a HP for space heating.
4. The proportion of homes in NS, which would return net positive savings (NPV & IRR) from a HP investment to displace HHO.

A model was developed in Microsoft Excel to support this investigation; the model inputs, such as technology performance of HPs and HHO, were informed by the literature review. Each research question posed its own unique caveats that required further model development and will be discussed in detail in the next sections. In general, the process to investigate these questions included:

- Determining the number and type of eligible homes in NS where it makes sense to install a HP.
- Developing ten separate home segments representative of the NS housing stock, with varying annual heating demand profiles.
- Calculating the annual GHG emissions for each home profile and segment by primary heating type (HP & HHO) today and 25 years into the future.

- Calculating the operating costs for each home profile and segment by heating type (HP vs HHO) today, and 25 years into the future.
- Calculating the return on investment (NPV & IRR) for each home profile using three different homeowner profiles ranging in cost of borrowing and perceived time value of money.

3.1 Study Design

3.1.1 Scenario Analysis. This research included scenario analysis and evaluation, and sensitivity testing in order to analyze the performance of HPs relative to HHO in terms of operating efficiency, GHG emissions and costs. Scenario analysis and evaluation as a methodology is used widely to evaluate climate change impacts of technological substitution and predict possible future outcomes. Alcamo (2008) summarizes scenario analysis and evaluation as, “the process of building scenarios, comparing them, and evaluating their expected consequences” (Alcamo, 2008, p. 3). The methodology is used to predict potential future outcomes based on inputs derived from informed assumptions, both qualitative and quantitative in nature, and tests to determine which inputs and assumptions the outcome is most sensitive to (Koswo, 2008). Scenario analysis is useful as it has the potential to be more comprehensive or inclusive of potential variables, flexible, and less expensive than undertaking large-scale field experiments (Alcamo, 2008), which is beneficial for this study considering the complexity of research questions and available data.

3.1.2 Scenario Generation. To understand the GHG emissions reduction potential in NS that would result from a shift from HHO to HPs, two primary scenarios were constructed:

Scenario 1 “As-is”: Homes currently heating with HHO continue to for the next 25 years, and all other space-heating parameters of the home remain constant. The HHO system provides 100% of the annual heating requirement.

Scenario 2 "NewHP": Homes currently heating with HHO displace it with a new HP, which delivers 80% of annual home heating, and the remaining 20% is delivered by the existing HHO system, with all other space-heating parameters held constant.

In constructing both scenarios it was important not to treat all currently occupied homes in NS as homogenous. There is substantial variation across the approximately 400,000 homes in NS (StatsCan, 2016) in terms housing unit age, size and equipment (NRCan, 2015c), and home energy-use behaviour; all contribute to variances in space heating demand. Consequently, data from Natural Resources Canada's (NRCan) Canada Energy Use Data Handbook (CEUDH) were used to characterize 10 home segments that vary in terms of annual heating demand (described further in the next section). This created a total of 20 sub-scenarios that required construction, to estimate the GHG emission reduction potential:

	10	Home segments
X	2	Scenarios (As-is versus NewHP)
=	20	HP Adoption Sub-Scenarios

Inputs relating to HP and HHO performance, GHG emissions and operating costs, are tested for sensitivity on these 20 adoption scenarios; the results are used to inform research questions 1, 2 and 3. For research question 4, which relates to the expected net savings of a HP investment, three additional profiles were created to account for variations in investment behavior. As noted in Chapter Two, investment behavior of individuals for energy efficiency upgrades such as HPs is well researched, with extensive proof of the existence of *the Gap* – why consumers refrain from seemingly economically beneficial investments (Figure 7) (Palmer & Walls, 2017; Gerarden et al., 2015; Gillingham & Palmer, 2014; Smith & Moore, 2010; Metcalf & Hassett, 1999). Due to the potential existence of the Gap in NS, it was important to not only test varying costs of borrowing, but also the existence of varying private discount rates to account for non-financial hurdles such as uncertainty, hidden costs, imperfect information and principal-agent issues (Figure 7). For this reason, three investor profiles were created using a range in cost of borrowing and perceived value of money (further described below) and applied to the 20 HP adoptions sub-scenarios, creating 60 economic case studies:

20 Adoption Scenarios
X 3 Household Investment Profiles
= 60 Individual Economic case studies of HP Adoption

3.1.3 Model Inputs, Assumptions and Sensitivity Analysis. The assumptions and data used to parameterize the model are informed by literature review and have varying degrees of precision and accuracy. In this regard, some inputs come from well-documented and robust data sources while others are less understood and rely on a limited number of best estimates. For example, the proportion of heating delivered by the HP compared to the supplemental existing HHO system, is estimated at 80% HP - 20% HHO annually. However, this is not a well-documented value and is probably highly variable due to the installation choices and energy-using behaviour of the homeowner. In addition, some parameters and assumptions have very little impact on the results while others have considerable influence. For example, the number of homes in NS in 2017 was informed by the 2016 Census, and the consequences of this estimate being inaccurate will have no measurable impact on 60% of the results and only a miniscule impact on the other 40%. Whereas, the GHG emission calculation of HPs can be deeply skewed if the assumptions of HP performance and NSP's emissions intensity are incorrect. Hence, there is a need for sensitivity testing of inputs. Sensitivity testing is useful when there are uncertainties surrounding input values and assumptions, as it tests how sensitive the model's outcome is to variations (Alcamo, 2008; Koswo, 2008).

A ‘most-accurate’ or ‘best estimate’ set of inputs are referred to as Standard Assumptions, and throughout their characterization were chosen to yield a conservative modeling outcome particularly for inputs with a higher degree of uncertainty and/or sensitivity. More specifically, the Standard Assumption model inputs were selected to result in the lowest amount of GHG emission or operating costs reductions for HPs and not overstate the potential savings. For example, the study’s Standard Assumption is to consider the highest allowable GHG emissions per year by NSP as the model input for the GHG intensity for electricity generation in NS, even though recently reported emissions data suggest NSP is emitting well under the allowable cap (NSP, 2016b). Table 4 provides a summary of the Standard Assumptions.

Table 4. Standard Assumptions

Model Input	HP		HHO		Additional HP Inputs		
	Value	Source	Value	Source	Model Input	Value	Source
% homes 2017	12.7%	NSP customer survey (NSP, 2015)	39%	NSP customer survey (NSP, 2015)	NSP emission intensity projection 2017-2027	-3.88%	(NSUARB, 2017; *Greenhouse Gas Emissions Regulations, 2009)*
Natural growth rate	7.6%	Growth rate from 1990 (NRCan, 2015e) to 2015 (NSP, 2015)	-1.24%	Growth rate from 1990 (NRCan, 2015e) to 2015 (NSP, 2015)	NSP emission intensity projection post 2027	HIGH	Demand follows reduction trend 2005-2026, emissions level off
NS home growth rate	0.08%	Long-term medium growth projection (CMHC, 2013)	0.08%	Long-term medium growth projection (CMHC, 2013)	January heat requirement (% of Annual)	16.3%	(NRCan, 2017d)
New construction rate	33%	Estimate	25%	Estimate	HP heating hours per day	8	(SEAI, 2012)
Efficiency (COP) / combustion efficiency, 2017	2.87	(NRCan, 2017a), then adjusted to NS climate (E.C., 2017)	78%	Typical heating system efficiencies (NRCan, 2012).	HP cooling penalty	0%	As per ENS evaluation report (ENS, 2016)
COP / efficiency improvement per year	0.01	Estimate	0.50%	Estimate	HP life expectancy (years)	15	(NRCan 2017a, ENS, 2016, PPUC, 2015)
Usage / displacement	80%	(NRCan, 2017a)	20%	(NRCan, 2017a)	Inflation rate	2.00%	Estimate
Cost per kWh / per Litre, 2017 (cents)	15.063	(NSP, 2017b)	91.60	(StatsCan, 2018)			
NSP emission intensity / HHO emission factor, 2017 (gCO2e/kWh)	759	(NSUARB, 2017; *Greenhouse Gas Emissions Regulations, 2009)*	268	(Environment Canada, 2013, Table A6-4)			

3.1.4 Model Software. Microsoft Excel (Excel) was utilized to build the study model and was chosen due to the researcher's familiarity with the software and also due to the data available. As discussed, the assumptions in the model were informed by the literature review and a "most accurate" set of inputs are identified and referred to as Standard Assumptions. The formulas in the Excel model were linked to the Standard Assumption inputs, which were summarized on one sheet. This made efficient to sensitivity test all inputs of the Standard Assumptions, without requiring modifications to the formulas. This allowed for efficient sensitivity testing on all inputs to investigate how the variations impacted the anticipated outcomes.

Other software programs were considered for the model, including NRCan's RETScreen (NRCan, 2019) and Palisade's @Risk (Palisade, 2019). NRCan's RETScreen is a clean energy management software system that allows users to assess a potential clean energy project in terms of technical and financial feasibility. It is an excellent program; however, the data source used for the basis of the model does not include enough house-specific data required by the RETScreen software. Additional data (or speculative assumptions) would have been necessary to utilize this software effectively. Pallisade's @Risk software was also considered, as it integrates easily with Microsoft Excel, and allows the user to build models with complex scenarios and generate simple outcomes to help with decision-making. However, due to the nature of the data used for the basis of the model, the Excel model did not integrate the @Risk software.

3.2 Quantifying GHG Emission Impacts

The process for addressing research question 1 and constructing the model will be described in detail in this section. This process will also outline the main steps taken to address research questions 2 and 3, which required the same process but with slight variations to the model (see §3.3 and §3.4 for model description). Research question 4 required a sub-set of new model parameters, and will be described in detail in section 3.5.

3.2.1 Defining Home Segments. There is substantial variation across the many homes in NS in terms of space heating requirements. To capture these variations, ten home segments were created to be representative of the varying annual heating demand profiles in the NS housing stock. Ten was chosen mainly due to the data available in NRCan's Comprehensive Energy Use Data Handbook (CEUDH), which provides aggregated data on housing characteristics, energy supply and demand, and consumption patterns specific to NS up to 2014 (NRCan, 2015c). The CEUDH reports home space heating annual energy requirement by the home's construction year, ranging from before 1946 to after 2011 (Table 5), and by housing stock – single detached, single attached, apartments, and mobile homes. This study excludes apartments from the analysis as most homeowners or tenants of condominium units or apartments do not have decision power over heating system choice. Mobile homes are also excluded since they represent only a small portion of the NS housing market at 3.90% (Table 5).

Table 5. NS Housing Stock Segmented by Year Built and Annual Heating Requirement (NRCan, 2015c)

Home Segment	Housing Stock (year built)	Total Homes	% of NS Home Population	Average Floor Space (m2)	Annual Heating Requirement (kWh / Home)
	Total	398,000	100.00%	145.98	19,869
	Single Detached	269,300	67.7%	160.04	23,210
1	Old (<1946)	44,165	16.4%	173.71	32,083
2	1946-1960	18,582	6.9%	141.49	23,611
3	1961-1977	32,585	12.1%	140.20	19,583
4	1978-1983	26,391	9.8%	150.25	15,194
5	1984-1995	60,593	22.5%	159.33	16,167
6	1996-2000	23,968	8.9%	152.85	13,167
7	2001-2005	25,045	9.3%	163.49	13,667
8	2006-2010	22,621	8.4%	173.38	13,167
9	2011-2014	15,619	5.8%	187.64	13,389
10	Single Attached	26,900	6.80%	167.29	20,653
	Apartments	86,400	21.70%	101.85	9,003
	Mobile Homes	15,400	3.90%	110.39	23,451

Although the CEUDH separates both single-detached and single-attached homes into nine categories by the home's construction year, this study did not include all nine categories of the single-attached homes (e.g. townhouses), because taken together, such homes represent less than 7% of the total NS home population (Table 5). Instead, Segment 10 is the average of all nine single-attached home categories, and is represented by an average annual heating requirement of 20,653 kWh per home. Single-detached homes, in contrast, represent almost 70% of all homes in NS. For this reason, the study included all nine categories provided by the CEUDH to create the nine additional home segments to be analyzed in the study (Table 5). The annual heating requirements for each segment, as provided by the CEUDH, form the model's basis for calculating fuel consumption estimates and associated GHG emissions.

3.2.2 Home Heating Sources NS. Determining the number of NS homes currently heated using HHO is imperative for estimating the provincial GHG emission impacts of an instantaneous transition to HPs. As noted, data available for heating system breakdown in the NS home market is limited and inconsistent. This study uses two sources of data to understand the market share of homes currently heating with HHO and HPs in NS (Figure 4).

The NSP 2015 customer survey of heating sources in NS revealed that only 40% of homes in NS heated with HHO (Figure 4). This is the 'Standard Assumption' used in the model, as it results in a smaller potential of conversions to HPs as compared to the NRCan report in which 51% of current NS homes heat primarily with HHO (NRCan, 2015e) (Figure 4). This was chosen in this manner because it represents the lesser opportunity for potential emissions reductions (40% possible conversions to HPs compared to a possible 51%), which is consistent with all Standard Assumptions in taking the conservative estimate when there is uncertainty. However, recognizing that the higher (51% of homes) 2015 NRCan result may also be a very reasonable reflection of reality in NS, the entire model was re-run as part of the sensitivity analysis.

3.2.3 GHG Emission Calculations. Greenhous gas emissions are quantified at the individual home level for all ten home segments, and then multiplied by the number of homes in each segment to get the aggregated provincial estimates. The methodology applied to quantify GHG emissions is the same as used in Canada's National Inventory Report (NIR). Canada is an Annex 1 Party of the United Nations Framework Convention on Climate Change (UNFCCC) and is thus required to report an annual summary of national GHG inventories, following a Common Reporting Format that expresses quantities in terms of carbon dioxide equivalent (CO_2e) (UNFCCC, 2000). The definitions and methodologies for reporting GHG emissions in the NIR are consistent with The United Nations IPCC 2006 Guidelines for National Greenhouse Gas Inventories Tier 3 approach (IPCC, 2006). The Tier 3 approach for stationary combustion is calculated as follows:

Eqn 1 $$Emissions = Fuel\ Consumption \times Emission\ Factor$$

Where:

Emissions = GHG emissions by type of fuel and technology
Fuel Consumption = amount of fuel combusted per type of technology
Emission Factor = emission factor of a given GHG by fuel and technology type

3.2.3.1 Emission Factor HHO. The Emission Factor is a region or country-specific emission factor for the fuel and technology being consumed or used. Canada's NIR provides a country-specific emission factor for HHO (light fuel oil 2) at 2755 grams of CO_2e per Litre, and was developed based on the heating value, carbon content and destiny (Table A6-4, ECCC, 2018b), and is consistent with the 2006 IPCC Guidelines for National Greenhouse Gas Inventories (IPCC, 2006). To convert to kWh, the common unit in this study, an energy content of 12.22 kWh per kg HHO (Engineering Toolbox, 2017) and a fuel density of 0.84 kg per Litre (Environment Canada, 2015; Environment Canada, n.d.) were applied:

$$\begin{aligned} \text{Emission Factor for HHO} &= (2.755 \text{ kg } CO_2e/L) / (12.22 \text{ kWh/kg} / 0.84 \text{kg/L}) \\ &= (2.755 \text{ kg } CO_2e/L) / (10.27 \text{ kWh/L}) \\ &= 0.268 \text{ kg } CO_2e/kWh \end{aligned}$$

3.2.3.2 Emission Factor HP. The Emission Factor for HPs depend on where the HP is operating and the emissions intensity of the electricity supply. Since NSP provides 95% of all generation, transmission and distribution of electricity across NS (NSP, 2017e), the emission intensity of NSP's electricity system was used as the Emission Factor for HPs. NSP reports historical data on emissions and power generation, and provides future projections. The NSP reported emissions include the total emissions from the stacks of all power plants (NSP, 2016b).

The GHG emissions intensity is calculated by taking the total GHG emissions produced divided by the total power generated, represented by the following equation:

Eqn 2 $$\text{Emissions intensity} = \text{Emissions} \div \text{Power Generation}$$

The study's model derives its Power Generation inputs directly from NSP forecasts. The Emissions input assumes that NSP will emit the maximum allowable GHG emissions per year which are capped under compliance periods until 2030 (NS DOE, 2015c). This is in contrast to the reality in which NSP has made considerable progress in reducing emissions in recent years and have come well under the allowable limits (NSP, 2016b). However, using the upper legal emissions limit was chosen to be consistent with all other model inputs that contain a relatively high level of uncertainty so as to not overstate the potential. By choosing conservative inputs, the output would reflect the minimal amount of emissions reduction possible from displacing HHO with HPs.

The model also projects NSP emissions intensity for the 25-year period covered in this study. These projections are slightly more complex but are necessary to answer research question 3, and will be discussed in detail in section 3.4.

3.2.3.3 Fuel Consumption HHO. The annual heating energy requirement per home provided by the CEUDH (Table 5) provides the model's basis for calculating Fuel Consumption estimates and associated GHG emissions. To calculate Fuel Consumption, the annual heating energy requirement per home is multiplied by an assumed combustion efficiency for HHO systems, using the following equation:

Eqn 3

$$\text{Fuel Consumption HHO} = \text{Annual Heating Requirement} \times \text{Combustion Efficiency}$$

The primary "as-is" scenario for this study assumes that a home will continue heating with the existing HHO system, and is not necessarily operating at the 2017 high efficiency upper limit of 98.5% (USDOE, 2017a). Average heating system efficiencies for various sources of HHO systems range as low as 60% (NRCan, 2012). The model applies an average efficiency of 78% for HHO homes in 2017, which is the average of the lower and upper limits of NRCan's estimates, and is also the efficiency used by NRCan to calculate heating system cost comparisons (NRCan, 2017e).

3.2.3.4 Fuel Consumption HP. The annual heating energy requirement per home provided by the CEUDH (Table 5) also provides the model's basis for calculating Fuel Consumption estimates and associated GHG emissions of HPs. Heat pump efficiency is more commonly measured by its coefficient of performance (COP), which is determined by dividing the energy output of the HP by the energy needed to operate the HP, at a specific temperature (NRCan, 2017a). Calculating Fuel Consumption of HPs uses a similar equation to HHO:

Eqn 4 $\text{Fuel Consumption HP} = \text{Annual Heating Requirement} \times \text{COP}$

According to NRCan, the coefficient of performance (COP) of air-source heat pumps at 10°C is ~ 3.3; at –8.3°C it is ~ 2.3 (NRCan, 2017a). The COP used in this model is estimated using linear interpolation of NRCan's two COP data points and then adjusting to reflect average NS daily temperatures during the heating season (October through May). NS daily temperatures were estimated using the monthly averages from 1981 to 2010 from three weather stations (Yarmouth, Halifax and Sydney) across the region.

An average COP of 2.87 was determined for 2017 and will be the value used as the Standard Assumption of the model. This is a conservative estimate compared to other energy modeling estimates and manufacturer performance estimates (NEEP, 2017b); it was chosen to be consistent with other model inputs where uncertainty exists. However, since the higher performance HP estimates may be a more accurate reflection of reality, a COP of 3.04 will be tested in the model and presented in the sensitivity analysis. This number was estimated using the same method of linear interpolation of two COP data points from the average of the 2017 NEEP manufacturer report (2.4 COP at -8.3°C, 3.4 COP at +8.3°C) and then adjusted to NS daily temperatures during the heating season. Note that these data points from the 2017 NEEP report are based on the HP operating at maximum capacity; the report also provides performance averages at minimum capacity which have an even higher average COP. The NRCan estimates do not mention the capacity of the HP.

3.2.4 Supplemental Heating. HPs do not operate efficiently at very low temperatures, so homes require supplemental heating systems for the coldest days of the year (NRCan, 2017a). For these reasons, HPs are typically sized to meet 80 to 90% of the homes heating load, in order to maximize efficiency (NRCan, 2017a). This is important to determine adequate HP capacity and to estimate total space heating energy consumption. The model assumes that HPs provide 80% of home heating, while the existing HHO system provides the supplementary 20%.

3.2.5 HP Cooling Penalty. Since most modern HPs provide a cooling mode, some researchers have applied a cooling penalty to home energy consumption and associated GHG emissions (Raynaud, Osso, Bourges, Duplessis, & Adnot, 2015). However, the objective of this study is to evaluate the potential GHG emission reductions associated with displacing HHO with HPs for heating purposes only. Therefore, a cooling penalty was note included; this is consistent with ENS evaluations of its HP energy reduction programs (ENS, 2016).

3.3 Electricity and Heating Oil Costs

Research question 2 relates to the individual home, so the same method is used to quantify GHG emission impacts from displacing HHO with HPs as was the case with question 1; however, in this instance the results are reported at the individual home level. To quantify operating costs, the Fuel Consumption calculation was modified and included an additional set of assumptions for fuel costs into the model. The present costs for heating oil and electricity in NS (as of October 2017) were input as the fuel costs in the model (StatsCan, 2018; NSP, 2017b). In addition, the NSP base service charge of $10.83 per month (NSP, 2017b) and HST (Provincial and federal sales tax combined) were added to the HP operating costs. Heating oil is exempt from provincial sales tax, so only the federal portion is included in the model (NRCan, 2017b). The operating costs for HHO and HPs in NS were calculated using the following equations:

Eqn 5

$$\text{Operating Cost HHO} = (\text{Fuel Consumption HHO} \times \text{Fuel Rate}) + \text{GST}$$

Eqn 6

$$\text{Operating Cost HP} = (\text{Fuel Consumption HP} \times \text{Electricity Rate}) + (\text{Base charge} \times 12\text{ months}) + \text{HST}$$

3.4 Future Projections

With emissions limits imposed on NSP to 2030 and ongoing investments in renewable electricity generation, it was important to reconstruct the model to take into account the changing emission intensity of electricity in NS going forward. The GHG emissions linked to the operation of a HP depends entirely on the generation sources of the electricity supply. Research question 3 addresses a 25 year future horizon to take into account the anticipated reductions in NSP generated GHG emissions and emissions intensity. This required further model development to include projection assumptions of the NS housing market, HHO and HP efficiency improvements, fuel and electricity costs, and of course NSP emissions intensity.

3.4.1 NS Housing Market Projections. Canadian Mortgage and Housing Corporation (CMHC) provides housing market growth projections based on population growth, headship rates[5] and economic development (CMHC, 2013). The model uses the CMHC medium growth scenario projection that provides an estimate every five years from 2016 to 2036. All newly constructed homes after 2014 – the last year of data provided by the CEUDH – are added to the Segment 9 heating energy profile (homes built between 2011 and 2014).

3.4.2 Fuel and Electricity Cost Projections. Electricity and heating oil costs are variable and will fluctuate over the projected 25-year period. Despite this, the Standard Assumption for heating oil and electricity prices were held constant (October 2017 data) over the 25 year projected period. While these prices are unlikely to stay constant, the fuel prices are considered constant relative to the alternative fuel choice. Put another way, the model assumptions are based on the notion that heating oil and electricity prices will fluctuate more or less in parallel over the 25 year period.

Sensitivity analyses were conducted to account for situations in which one fuel cost fluctuates more widely than the other. Price variations applied in the sensitivity tests were informed by historical price trends and variations. Four price variations of heating oil prices were tested for sensitivity compared to three variations for electricity prices, due to greater fluctuation in heating oil prices in the last five years in NS (StatsCan, 2018; NSP, 2017b). The following sensitivity analyses were conducted:

Oil price increase over time:

- Applies a 1.69% price increase year over year; reflective of the ten year annual growth rate from 2007 to 2016 (StatsCan, 2018).

Oil price increase #1:

---

[5] an age-specific headship rate is the rate at which people in a given age group form households, and is calculated as the number of primary household maintainers in that age bracket divided by the total number of people in the same age bracket (CMHC, 2013).

- Applies a 5 cent increase to 96 cents per Litre, the 3 year average from 2014-2017

Oil price increase #2:

- Applies a price increase to 103 cents per Litre, the average of the projected prices from 2017 to 2042, based on +1.69% per year.

Oil price decrease:

- Applies the two year average decrease in price from Sept 2015 to Sept 2017 (when oil prices fell), at 90 cents per Litre.

Electricity price increase over time:

- Applies a 2.83% price increase year over year; reflective of the ten year annual growth rate from 2010 to 2019 (NSP, 2017)

Electricity price increase:

- Applies a price increase to 18.10 cents per kWh, the average rate of the projected prices from 2017 to 2042, based on +2.83% per year.

Electricity price decrease:

- Takes into account an electricity price decrease, and applies the average price between 2010 and 2019, at 14.33 cents per kWh.

3.4.3 Equipment Efficiency Improvements. The technological efficiency limits are not believed to have been reached for HPs. The model assumes an efficiency improvement of 0.01 COP per year to all new installed HPs, reaching an average heating season COP of 3.12 by the end of the 25 year time horizon modeled in this study. For HHO, it is anticipated that the technology has reached maximum combustion efficiency, considering modern systems already achieve 98.5% combustion efficiency (USDOE, 2017a). However, an average efficiency increase of 0.50% per year for all HHO systems was used to represent the expectation that older systems will be replaced with newer systems over the 25 year period. The overall average of HHO efficiency reaches 90.5% combustion efficiency by the end of the model's period.

3.4.4 NSP Emissions Intensity Projection. The same process and formula (Eq2) is followed to project NSP emission intensity into the 25 year future. However, additional sensitivity analyses were conducted for the years 2026 to 2042, the years beyond NSP forecasts or currently defined emissions cap compliance periods. NSP electricity demand forecasts did not exist beyond 2026 and the emission cap compliance period ends in 2030 (NSUARB, 2017b; NS DOE, 2015c). Since emissions intensity is highly variable and depends on electricity demand and the generation mix of renewable energy relative to traditional fossil fuel sources (NSP, 2016b), it was necessary to conduct four sensitivity tests beyond 2026 and 2030, and are defined as follows:

Power Projection A = No electricity demand change after 2026
Power Projection B = Demand follows reduction trend 2005-2026 (-0.26%/year)
Emissions Projection A = No decline after 2030
Emissions Projection B = NSP continues emission reduction trend 2010-2030 (-3.59%/year)

3.5 Return on HP Investment

An additional set of model inputs and calculations are required to address research question 4, which seeks to explore the return on investment for individual households that chose "NewHP" (scenario 2) rather than remain "As-is" (scenario 1). Ranking investments requires establishing a criteria to measure them; two commonly used financial indexes to rank investments include net present value (NPV) and internal rate of return (IRR) (Kuchta, 2000). The NPV indicator was chosen because it takes uncertainty into consideration: it is the sum of discounted revenues less the sum of discounted costs over a defined period and is sensitive to the discount rate used for analysis (Bas, 2013). The IRR is a metric commonly used to evaluate the profitability of investments that are large in nature and are long-term; it essentially uses the same equation that is used to calculate NPV but sets the discount rate that makes the NPV of all cash flows of the investment equal to zero (Investopedia, 2017; Juhász, 2011):

Eqn 7

$$\mathrm{NPV} = \sum_{t=1}^{T} \frac{C_t}{(1+r)^t} - C_o$$

Where:

Ct = net cash inflow (savings) of operating HP each year
Co = total initial investment costs of HP
r = discount rate
T = number of time periods (15 years)

The time period (T) in this study is 15 years, which is the typical lifetime used for measuring GHG emission reductions of a HP (ENS, 2016; PPUC, 2015), despite HPs often lasting more than 20 years (NEEP, 2017a; ENS, 2017f; NRCan, 2017a). This was chosen to keep consistent with Standard Assumptions to not overstate the potential reductions.

The net cash inflow (Ct) considers the operating cost savings and the borrowing costs of the total initial HP investment cost (Co). The operating costs savings were calculated using similar processes and formulas applied in quantifying the operating costs for residential homes addressed in research question 3. In this instance, only the operating cost impacts in the first 15 years are considered. To account for borrowing costs, the model factors in the cumulative interest payments for two types of home borrowers: 1) those with access to traditional mortgage products; and 2) those who do not and rely on NSP financing[6]. The two profiles range in interest rate and repayment length. Maintenance costs for both HPs and HHO were not considered in the model.

---

[6] NSP offers financing for HPs to all customers on approved credit (NSP, 2017c)

To calculate total initial investment costs (Co) for the HP, the appropriate size of HP was first estimated for each home segment using the following formula:

Eqn 8

$$Power\ (kW) = Energy\ (kWh)\ /\ time\ (hours)$$

The energy requirement (kWh) per home segment is provided on an annual basis by the CEUDH (Table 5). However, the HP does not operate all year round; the majority of the annual heating requirement will be delivered in the coldest months. For this reason, the model sized HPs per home segment based on the heating requirement of the coldest month of the year – January. Average heating degree-days (HDD) in January in Halifax between 1980 and 2010 represent 16.3% of total average annual heating requirement during that same period (NRCan, 2017d). In addition, HPs do not operate continuously 24 hours a day, they use instantaneous power at different speeds, delivering heat intermittently with cut-out periods throughout the day. For this reason, the model was developed to follow the guidelines of the Sustainable Energy Authority of Ireland, which uses a heating schedule for HPs of 8 hours per day in their Dwelling Energy Assessment Procedure (DEAP), and 16 hour cut-out periods (SEAI, 2012). The DEAP method was chosen mainly due to the nature of the data used in this study which is not specific enough for HP sizing methods found in Canada. There is a recognized HP sizing method in Canada provided by the Standards Council of Canada (Standards Council of Canada, 2009), and also NRCan provides an online HP pre-screening tool that offers guidance on the feasibility of a HP investment including upfront costs (NRCan, 2017d). However, these methods and tools require individual home and energy-using characteristics that is beyond what is provided by the CEUDH and used as the basis of the model calculations (Table 5).

Since HPs in cold climates such as NS are typically sized to meet 80 to 90% of the heating load (NRCan, 2017a), the model considers HPs to provide 80% of home heating while the existing HHO system provides the supplementary 20%. An example of a Segment 1 home HP sizing calculation is as follows:

Power (kW) = Energy (kWh) / time (hours)
kW = (32,083 * 16.3%) / (31 days * 8 hours/day) * 80% HP usage
kW = 16.9 kW.

A 16.9 kW HP would adequately supply 80% of the heat required during January for Segment 1 homes.

The home segments with higher heating demands are assumed to require larger HPs to adequately deliver the annual heating requirement, and subsequently will result in higher upfront costs of installation. An average cost of installation per size of HP was estimated using the best available data: the NEEP 2017 follow-up report which provides installation costs from thirteen reports throughout the Northeast United States published between 2012 and 2016 (NEEP, 2017a). The average of the reported installation costs were calculated and then converted to Canadian dollars during the same time frame.

Choosing a discount rate (r) took careful consideration, due to the many reasons outlined in the literature review relating to *the Gap*. As previously noted, non-financial costs such as uncertainty, hidden costs, imperfect information, and principal agent issues to name a few, result in highly varying perceptions and expectations of future savings to the individual homeowner (Giraudet & Houde, 2015; Michelsen & Madlener, 2015; Clinch & Healy, 1999). If these non-financial costs are overlooked in the analysis, it can result in an overstated expectation of net over savings of the HP investment (Giraudet & Houde, 2015; Michelsen & Madlener, 2015; Clinch & Healy, 1999).

Discount rates for model-based calculations of energy efficient investments often apply social discount rates or subjective discount rates. Social discount rates typically reflect only the time preference and decreasing marginal utility of the investment (Schleich, et al., 2016). Subjective discount rates (or implicit discount rates) on the other hand, also include external barriers to energy efficiency typically outlined in *the Gap* literature (Schleich et al, 2016; Hermelink & de Jager, 2015; Jaffe & Stavins, 1994). For these reasons, it was necessary to build these non-financial costs into a subjective discount rate, and then test at multiple rates. Three homeowner investor profiles were created ranging in discount rate (and cost of borrowing) to account for the potential presence of *the Gap* in HP investment in NS, and to not overstate potential savings:

- **Investor 1 (Informed, Low Cost)**– represents a best-case scenario as it assumes the individual is well informed of the benefits of a HP and has access to current low cost borrowing products such as a mortgage or secured line of credit. Since the homeowner is well informed, the barriers to the take up of HPs highlighted in *the Gap* are expected to be minimal, so the discount rate chosen reflects only the cost of borrowing – 3.15%. At the time of this study (November 2017), 3.15% represents a modestly discounted fixed mortgage rate (RateSupermarket.ca, 2017). A typical repayment period of 25 years was chosen.
- **Investor 2 (Informed, Higher Cost)** – represents an individual who is informed of the benefits of HPs and not likely influenced by barriers related to *the Gap*; however, does not have access to low cost mortgage products. NSP currently offers financing for HPs to all homes in NS with a good standing NSP account, at 7% interest and with 2-10 year repayment term options (NSP, 2017c). This profile applies a 7% interest rate and 6-year repayment term, which is the median of the NSP options. A 7% discount rate was chosen to reflect the cost of borrowing.

- **Investor 3 (Not-Informed, Higher Cost)** – represents an individual is borrowing through NSP financing at 7% interest over 6 years, since all homes in NS with good account standing have this option. A 10% discount rate is applied to include the potential barriers to the uptake of HPs, as highlighted in *the Gap* literature.

Chapter 4: Presentation of Results

4.1 Provincial GHG Emission Impacts

Research question 1 aimed to quantify the net annual GHG emissions impact if all residential homes space heating with HHO in 2017 were converted instantaneously to an electric air-source HP in NS. As discussed in Chapter 3 section 3.2, GHG emissions were quantified at the individual home level for all ten home segments, and then multiplied by the number of homes in each segment to get the aggregated provincial estimates. Table 6 presents the individual home results for all ten homes and home segments.

Table 6. Annual Residential Heating GHG Emissions Emitted by HPs and HHO in NS in 2017 per Home and Home Segment

Home Segment	GHG Emissions (tCO_2e/home)			Number of Homes in Segment	Home Segment Reduction Potential (GHG Emissions)
	HHO Primary (Scenario 1)	Install HP Primary (Scenario 2)	Reduction Potential per Home		
1	11.04	8.99	2.05	17,233	35,328
2	8.12	6.62	1.50	7,251	10,877
3	6.74	5.49	1.25	12,715	15,894
4	5.23	4.26	0.97	10,298	9,989
5	5.56	4.53	1.03	23,643	24,352
6	4.53	3.69	0.84	9,352	7,856
7	4.70	3.83	0.87	9,773	8,503
8	4.53	3.69	0.84	8,827	7,415
9	4.61	3.75	0.86	6,095	5,242
10	7.11	5.79	1.32	10,496	13,855

The home segments with higher heating demand profiles, such as Segment 1 homes built before 1946, will result in higher GHG emission reductions due to the efficiency advantages of HPs relative to HHO. For example, there are 23,643 Segment 5 homes (built between 1984-1995) on HHO in 2017, compared to 17,233 homes on HHO in Segment 1, and yet, Segment 1 represents a collective reduction opportunity of 35,328 tCO_2e compared to 24,352 tCO_2e in Segment 5 (Table 6).

Table 7 presents the cumulative Provincial GHG emission impacts if all residential homes space heating with HHO instantaneously adopt a HP, and also provides sensitivity analysis on some key inputs that influence the results. With the Standard Assumptions applied throughout the model, results of the analysis reveal there would be a cumulative total reduction in GHG emissions of ~140,000 tCO_2e in 2017 (Table 7). According to the US Environmental Protection Agency (EPA), this is the equivalent emissions output of driving almost 30,000 standard passenger vehicles continuous for one year (EPA, 2017).

Because of their influence in the model, three of the Standard Assumptions were isolated for sensitivity analysis and presented in Table 7:

1) Number of homes in NS on HHO in 2017 is increased to that of the NRCan estimate (from 40% to 51% -- see §3.2.2). The Standard Assumption uses the NSP customer survey to stay consistent with choosing the option that would result in fewer emissions reductions when there is uncertainty; however, the NRCan estimate may also be a reasonable reflection of the reality in NS, which could result in more conversions.
2) Nova Scotia Power emissions intensity is reduced to reflect the reported NSP 2016 emissions intensity rather than the legislated maximum allowable GHG emissions applied in the Standard Assumption (see §3.2.3.2)
3) Heat pump performance (COP) is reduced to understand where the conversion no longer makes sense in terms of GHG emissions reductions, and is presented in sensitivity analysis 3.

Table 7. Cumulative Provincial GHG Emissions of Residential Home Heating in NS

Model	Number of Homes on HHO 2017	Cumulative Annual GHG Emissions (tCO_2e)		
		HHO Primary (Scenario 1)	HP Primary (Scenario 2)	Reduction Potential
Standard Assumptions	115,682	757,790	617,291	140,499
Sensitivity analysis:				
1) NRCan Heating Sources	150,903	986,490	803,588	182,902
2) 2016 Actual NSP Emissions Intensity	115,682	757,790	581,281	176,509
3) HP Annual Average COP decrease to 2.21	115,682	757,790	757,860	- 70

Sensitivity analyses 1 revealed that the GHG emissions reduction potential of displacing HHO with HPs increases to ~183,000 tCO_2e per year if the model calculations included NRCan's estimate for number of homes on HHO, an increase of over 42,400 tCO_2e in emission reduction potential. Additionally, when the actual NSP emissions intensity from 2016 is applied in sensitivity analysis 2, the reduction potential of displacing HHO with HPs increases to ~176,500 tCO_2e per year, an increase of over 36,000 tCO_2e in emissions reduction potential. These results are not surprising, since the Standard Assumptions use conservative estimates that would result in less GHG emissions reductions: less homes on HHO will result in fewer opportunities to switch to HPs, and a higher NSP emissions intensity will result in higher emissions.

4.2 GHG Emissions and Operating Cost Impacts per Home

Research question 2 aimed to quantify the net annual GHG emissions and operating cost impacts for individual residential homes in NS, who displace HHO with HPs for space heating in 2017. As discussed in section 3.3, the process for addressing research question 2 in terms of

GHG emissions was similar to research question 1, but in this case the results and sensitivity analysis are reported at the individual home level (Table 8).

An additional set of fuel cost assumptions were added to the model to quantify the operating cost impacts of displacing HHO with HPs in NS. The present cost of heating oil (92 cents per Litre) and electricity (15.063 cents per kWh) in NS (as of October 2017) were the Standard Assumptions applied in the model. In addition, the NSP base service charge of $10.83 per month (NSP, 2017b) and HST were added to the HP operating costs. Heating oil is exempt from provincial sales tax (NRCan, 2017b), so only the federal portion is included in the model. Table 8 presents the individual home impacts of displacing HHO with HPs in 2017 for all ten home segments in terms of GHG emissions and operating costs, based on the Standard Assumptions.

Table 8. Annual Residential Heating GHG Emissions and Operating Costs of HPs and HHO in NS in 2017 per Home

Home Segment	GHG Emissions (tCO_2e/home)			Operating Costs per Home		
	HHO Primary (Scenario 1)	Install HP Primary (Scenario 2)	Reduction Potential per Home	HHO Primary (Scenario 1)	Install HP Primary (Scenario 2)	Reduction Potential per Home
1	11.04	8.99	2.05	$3,853	$2,332	$1,521
2	8.12	6.62	1.50	$2,836	$1,720	$1,116
3	6.74	5.49	1.25	$2,352	$1,428	$924
4	5.23	4.26	0.97	$1,825	$1,111	$714
5	5.56	4.53	1.03	$1,942	$1,181	$761
6	4.53	3.69	0.84	$1,581	$964	$617
7	4.70	3.83	0.87	$1,641	$1,001	$640
8	4.53	3.69	0.84	$1,581	$964	$617
9	4.61	3.75	0.86	$1,608	$981	$627
10	7.11	5.79	1.32	$2,480	$1,506	$974

Results reveal that the highest reductions in GHG emissions and operating costs are achieved in homes with higher heating demands, such as Segment 1 homes built before 1946.

The installation of a HP to displace HHO in this home segment is estimated to reduce annual GHG emissions by 2.05 tCO_2e and operating costs by $1521, in 2017 (Table 8). Heating costs are typically incurred between October and May in NS, so the $1521 in expected annual savings will translate to approximately $190 per month per home during the heating season.

Table 9 presents the average GHG emissions and operating cost impacts for individual residential homes in NS, who displace HHO with HPs for space heating in 2017, and also provides sensitivity analysis on inputs that influence individual home results. With the Standard Assumptions applied throughout the model, results of the analysis reveal that displacing HHO with a HP for residential home heating in NS is estimated to reduce annual GHG emissions by 1.16 tCO_2e and $851 in operating costs, on average per home (Table 9).

The assumed number of homes on HHO in NS was omitted from the sensitivity analysis of research question 2 as it is only relevant to cumulative home emissions. Therefore, Table 9 presents two of the Standard Assumptions isolated for sensitivity analysis, relating to NSP emissions intensity and HP performance:

1) NSP emissions intensity is reduced to reflect the reported NSP 2016 emissions intensity rather than the legislated maximum allowable GHG emissions applied in the Standard Assumption (see § 3.2.3.2)
2) HP performance (COP) is reduced to understand where the conversion no longer makes sense in terms of GHG emissions reductions. Sensitivity analysis 3 presents the results with a HP COP of 2.21 (compared to 2.87 applied in the Standard Assumption).

Table 9. Average Annual Residential Heating GHG Emissions and Operating Costs of HPs and HHO in NS in 2017 per Home

Model	GHG Emissions (tCO_2e/home)			Operating Costs per Home		
	HHO Primary (Scenario 1)	HP Primary (Scenario 2)	Reduction Potential	HHO Primary (Scenario 1)	HP Primary (Scenario 2)	Reduction Potential
Standard Assumptions	6.22	5.06	1.16	$2,170	$1,319	$851
Sensitivity analysis:						
1) 2016 Actual NSP Emissions Intensity	6.22	4.77	1.45	$2,170	$1,319	$851
2) HP Annual Average COP decrease 2.21	6.22	6.22	0.00	$2,170	$1,579	$591

The results are as expected; if NSP emissions intensity is more like 2016 actual reported emissions intensity, compared to the 'worst-case' Standard Assumption which assumes NSP will emit the maximum legislated allowable emissions, the anticipated average annual GHG emissions reductions increases from 1.16 tCO_2e to 1.45 tCO_2e on average per home (Table 9). The operating costs of HHO and HPs are not impacted by the emissions intensity of NSP, hence, the same outcome for operating costs savings in sensitivity test 1 compared to the Standard Assumptions (Table 9). However, if the HP underperforms to an average annual COP of 2.21, there are no expected GHG emissions reductions, and the operating cost savings are reduced to $591 per year per home in 2017when all other Standard Assumptions apply (Table 9).

4.3 Energy, Cost and Emission Impacts over next 25 years

Research question 3 aimed to quantify the energy consumption, operating cost and emission impacts over the next 25 years, for individual residential homes in NS, who displace HHO with a HP for space heating. As discussed in Chapter 3 section 3.4, research question 3 addresses a 25 year future horizon to take into account the anticipated reductions in NSP generated GHG emissions and emissions intensity. This required further model development to include projection assumptions of the NS housing market, HHO and HP efficiency improvements, fuel and electricity costs, and of course NSP emissions intensity.

Figure 9 presents the results of the NSP emissions intensity projection. Nova Scotia Power GHG emission intensity decreases from 759 gCO_2e per kWh in 2017 to 511 gCO_2e per kWh in 2027, Beyond NSP's 2027 power generation estimate and 2030 emission cap requirements, four different circumstances were considered to assess the influence on the GHG emissions intensity projections to 2042

Power Projection A = No power demand change after 2027
Power Projection B = Demand follows reduction trend 2005-2027 (-0.26%/year)
Emissions Projection A = No decline after 2030
Emissions Projection B = NSP continues emission intensity reduction trend 2010-2030 (-3.59%/year)

All combinations were tested using Eq 2[7] to produce varying GHG emission intensities through 2042; two combinations are presented in Figure 9 which represent the highest (HIGH Projection) and lowest (LOW Projection) emissions intensity projection, of the four combinations considered.

---

[7] Eq 2: *Emissions intensity = Emissions ÷ Power Generation*

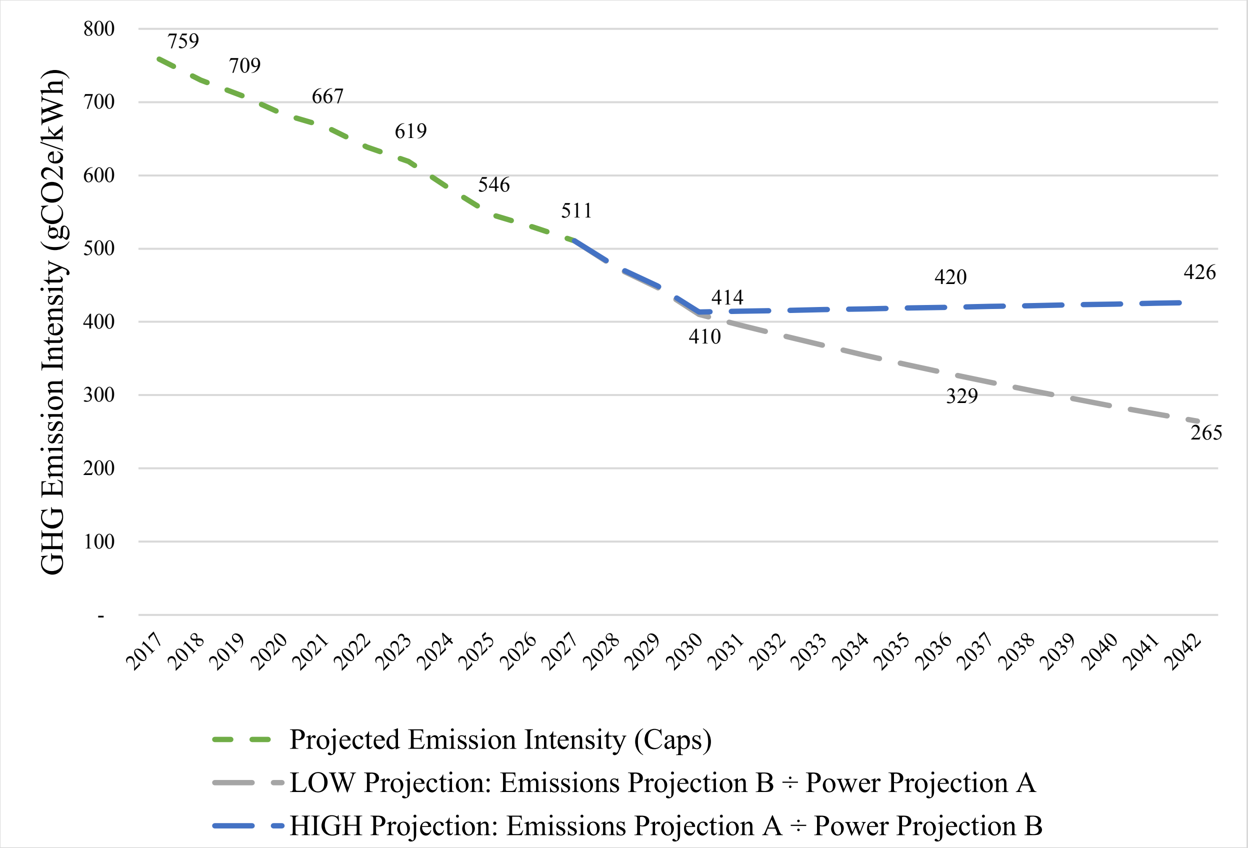


Figure 8. NSP emissions intensity forecast, 2017-2042

The HIGH Projection (Emissions Projection A ÷ Power Projection B) is the Standard Assumption, to stay consistent with all other model inputs, in choosing the option which results in the lowest HP related emissions reductions. This projection decreases from 475 in 2028 to 414 gCO_2e/kWh in 2030 under the existing emission cap compliance period, then increases slightly to 426 gCO_2e/kWh by 2042, due to anticipated lower demand and no emission generation intensity decline post 2030 (Figure 9). The LOW Projection (Emissions Projection B ÷ Power Projection A) which decreases to 265 gCO_2e/kWh in 2042, will be applied in sensitivity analysis 1, to determine the GHG emissions reduction potential if NSP continues to reduce its average GHG emission intensity (Figure 9).

Table 10 presents the average of all ten home segments in terms of annual energy use and operating cost savings opportunity, and GHG emission reduction potential, from 2017 to 2042 based on Standard Assumptions, and also provides sensitivity analysis on some of the key inputs. The annual GHG emissions reduction potential of displacing HHO with HPs increases into the future as NSP emissions intensity is projected to decline (HIGH Projection), from an average reduction per home of 1.16 tCO_2e in 2017 to 2.50 tCO_2e in 2042 (Table 10). The switch to HPs is also expected to reduce energy consumption by 13,495 kWh annually and reduce operating costs by $851, on average per home in 2017 (Table 10). The savings potential of energy consumption and operating costs are highest in 2017 (13,495 kWh & $851), and decline into the future as the projected HHO efficiency improvements are greater than the relative gains in average HP efficiency (Table 10). Recall, this is because the assumption made was that in 2017 the HHO systems are older and have a lower efficiency average with more upside improvement potential, compared to HPs which are assumed to be recently installed and operating at the typical 2017 COP of 2.87. The resulting average energy and operating cost savings decline to 11,339 kWh and $716 annually in 2042 (Table 10).

The GHG emissions reduction potential per home under the Standard Assumptions increase from 1.15 tCO_2e in 2017 to its highest in 2030 at 2.70 tCO_2e, but the reduction potentials are not as large post 2030 (Table 10). This is because while there are ongoing GHG emissions caps imposed on NSP's electricity generation through 2030, after this date, it was assumed that no further emissions intensity reductions will occur as part of the Standard Assumptions. Consequently, the average annual home GHG emission reduction opportunity that results from displacing HHO with HP's increases from 1.15 tCO_2e in 2017 to 2.50 tCO2e in 2042 (Table 10).

Due to their influence in the model related to future projections, four of the Standard Assumptions were isolated for sensitivity analysis and presented in Table 10:

1) Nova Scotia Power emissions intensity LOW Projection. To understand the emissions impacts in the event that NSP continues steadily decreasing its emissions intensity trend post 2027.
2) Heat pump performance (COP) reduction. Average annual COP is reduced from 2.87 to 2.21 in the model - the point at which displacing HHO with a HP no longer results in any GHG emission reductions in 2017.
3) Electricity cost increase. A 2.83% price increase year over year is applied; reflective of the ten year annual growth rate from 2010 to 2019 (NSP, 2017). The heating oil price remains constant at the 2017 price.
4) Heating Oil price increase. A 1.69% price increase year over year is applied; reflective of the ten year annual growth rate from 2007 to 2016 (StatsCan, 2018).

Table 10. Average Annual Energy Use and Cost Savings Opportunity and GHG Emissions Reductions per Home over the next 25 years

		Average Annual Savings or Emissions Reduction Opportunity, per home				
Models		2017	2025	2030	2035	2042
Standard Assumptions	Energy (kWh)	13,495	12,728	12,288	11,875	11,339
	Costs ($ CDN)	$851	$824	$790	$758	$716
	GHG Emissions (tCO_2e)	1.16	2.05	2.70	2.47	2.50
Sensitivity analyses:						
1) LOW NSP Emissions post 2027	GHG Emissions (tCO_2e)	1.16	2.05	2.72	2.84	3.09
2) HP Annual Average COP decrease to 2.21	GHG Emissions (tCO2e)	0.00	1.27	2.13	1.92	2.02
3) Electricity cost increase +2.83%	Costs ($ CDN)	$851	$658	$494	$316	$41
4) Heating oil price increase + 1.69%	Costs ($ CDN)	$851	$1,049	$1,160	$1,278	$1,456

In the event that NSP continues steadily decreasing its emissions intensity trend post 2027 (LOW NSP Emissions post 2027), the emissions-reduction opportunity of displacing HHO with a HP increases to 3.09 tCO_2e by 2042 for the average home, compared to 2.50 tCO_2e per home under the Standard Assumption (Table 10).

HP performance (as expressed in terms of annual average COP) will, not surprisingly, influence the anticipated GHG emission reduction potential of displacing HHO. Table 7 presents results of model outcomes in which average annual COP is reduced from 2.87 to 2.21 in the model - the point at which displacing HHO with a HP no longer results in any GHG emission reductions, in 2017. However, emissions reductions could be as much as 2.02 tCO_2e per home by

2042 (Table 10). This is due to the anticipated decline in NSP emissions intensity under the Standard Assumption HIGH Projection.

If NSP's price of electricity continues its ten-year upward trend of increasing at an annual rate of 2.83% while heating oil prices remain constant, the operating cost savings potential of displacing HHO with a HP becomes effectively negligible by 2042, at $41 annually (Table 10). However, if electricity prices remain constant while heating oil prices in NS increase relative to the recent ten-year average annual increase of 1.69%, the operating costs savings of displacing HHO with a HP increase to $1456 per home per year in 2042 (Table 10).

4.4 Return on HP Investment to Displace HHO

Research question 4 aimed to quantify the proportion of homes in NS, which would return net positive savings (NPV & IRR) from a HP investment to displace HHO. As described in Chapter 3 section 3.5, this research question involved a new set of model assumptions including the appropriate size of HP and associated installation costs (labour & equipment) per home segment, and creating three investor profiles to account for the variances in investment behaviour, non-financial and financial costs. Table 11 presents the results of the installation cost estimates (labour & equipment) per home segment. Recall, the size of the HP was estimated based on delivering the heating needs in the coldest month of the year, January, which on average requires 16.3% of the total annual heating requirement in NS (NRCan, 2017d). Assuming the HP operates continuously for 8 hours per day, and there are 31 days in January; therefore, a 21.1 kW HP is required to deliver the January heating requirement for Segment 1 homes (Table 11). However, since it is recommended that HPs are sized to meet 80% of the heating load (NRCan, 2017a) while the backup system provides the supplementary 20%, the adequate HP size for Segment 1 homes is estimated at 16.9 kW (Table 11). Not surprisingly, the home segments with higher annual heating requirements require larger capacity HPs (Table 11).

An average cost of installation per size of HP was estimated for all ten home segments using the best available data: the average of thirteen reports generated in various settings throughout the Northeast United States published between 2012 and 2016 and then converted to Canadian dollars (Table 11). Recall, there is a small economies of scale associated with the installation of HP's in that homes that require larger HPs benefit from a lower cost per HP capacity installed. For example, Segment 1 homes require a 16.9 kW HP, almost double the size of a Segment 5 home (8.5 kW HP); however, the cost of installation ($12,369) for Segment 1 homes is less than double that of Segment 5 homes ($7281) (Table 11).

Table 11. HP Installation Cost (Labour & Equipment) by Home Segment

Home Segment	Annual Heating Requirement (From CEUDH) (kWh)	January Heating Requirement (16.3% of Annual) (kWh)	HP Capacity to Deliver January Requirement (kW)	Sized to Deliver 80% of Heating Requirement (kW)	Cost per kW (From NEEP Report)	Total Installation Cost (Labour & Equipment
1	32,083	5,236	21.1	16.9	$732.25	$12,369
2	23,611	3,854	15.5	12.4	$797.84	$9,918
3	19,583	3,196	12.9	10.3	$829.02	$8,548
4	15,194	2,480	10.0	8.0	$863.00	$6,904
5	16,167	2,639	10.6	8.5	$855.47	$7,281
6	13,167	2,149	8.7	6.9	$878.70	$6,091
7	13,667	2,231	9.0	7.2	$874.83	$6,295
8	13,167	2,149	8.7	6.9	$878.70	$6,091
9	13,389	2,185	8.8	7.0	$876.98	$6,182
10	20,653	3,371	13.6	10.9	$820.74	$8,924

The individual household return on investment as expressed as net present value (NPV) from displacing HHO with a HP in NS is presented in Table 12 for all investor profiles and home segments using the Standard Assumptions. Results revealed that all homes in the Investor 1 profile (Informed, low-cost) will experience a positive NPV on their HP investment, compared to just 15% of homes under the Investor 2 profile (Informed, higher-cost) which are all concentrated in home segment 1 (Table 12). Importantly, when higher borrowing costs and low knowledge conditions prevail, as modeled using the Investor 3 profile (Not-informed, higher-cost), no home segments experienced a positive NPV (Table 12). For households in which knowledge is high and borrowing costs are low (Investor 1 profile homes) consequently achieve both positive NPV and IRR on a HP investment across all home segments, greater savings are achieved in home segments with higher annual heating requirements, such as Segments 1, 2, 3 and 10 (Table 12). Investor 1 profiles in other home segments should also consider a HP, but the expected net savings are not as high (represented in orange). The case is not as strong from an investment standpoint and will be more sensitive to electricity price fluctuations and HP performance.

The outlook for the Investor 2 profile (Informed, higher-cost) is not as positive and will only realize a minimal net positive savings on their HP investment in Segment 1 homes, which make up 15% of the representative home population (Table 12). The Investor 3 profile (Not-informed, higher-cost), which a) builds into the discount rate the potential barriers highlighted in *the Gap,* and b) also borrow using NSP financing, will not achieve a net positive savings on their HP investment regardless of the segment (Table 12).

Table 12. Return on Investment: Displacing HHO with a new HP vs No Installation, by Borrower Profiles and Home Segments

Investor Profile:	1: Informed, Low-cost		2: Informed, Higher-cost		3: Not-informed, Higher-cost	
Financing Terms:	3.15%, 25 Year Amortization		7.00%, 6 Year term		7.00%, 6 Year term	
Discount Rate:	3.15%		7.00%		10.00%	
Home Segment ↓	IRR	NPV	IRR	NPV	IRR	NPV
1	3.79%	$3,908	0.84%	$843	-1.91%	-$1,696
2	2.18%	$1,739	-0.49%	-$385	-3.20%	-$2,238
3	1.46%	$984	-1.08%	-$724	-3.78%	-$2,253
4	0.68%	$362	-1.70%	-$914	-4.38%	-$2,092
5	0.85%	$481	-1.56%	-$888	-4.25%	-$2,144
6	0.31%	$145	-1.99%	-$939	-4.66%	-$1,955
7	0.40%	$194	-1.92%	-$937	-4.59%	-$1,993
8	0.31%	$145	-1.99%	-$939	-4.66%	-$1,955
9	0.35%	$167	-1.96%	-$938	-4.63%	-$1,972
10	1.65%	$1,167	-0.92%	-$649	-3.62%	-$2,264
% of homes net positive savings →	100%		15%		0%	

The anticipated net savings from displacing HHO with a HP is heavily influenced by HP performance and fuel price fluctuations, and are isolated for sensitivity testing and presented in Table 13:

1) HP Performance (COP):
   i. Presents a *decrease* in average annual HP COP from 2.87 to 2.41 which is the point at which all homes under all profiles no longer achieve a positive NPV.
   ii. An *increase* in average annual HP COP from 2.87 to 3.04 is applied, which is the average COP from the 2017 NEEP report at maximum capacity after adjusting to reflect average NS daily temperatures during the heating season (see Chapter 3, § 3.2.3.4).

2) Electricity prices:
    i. Takes into account an electricity price *decrease*, and applies the average price between 2010 and 2019, at 14.33 cents per kWh.
    ii. Applies a price *increase* to 18.10 cents per kWh, the average rate of the projected prices from 2017 to 2042, based on +2.83% per year.
3) Heating oil prices:
    i. Applies a *decrease* in price, representing the two year average from Sept 2015 to Sept 2017 (when oil prices fell), at 90 cents per Litre.
    ii. Applies a 5 cent *increase* to 96 cents per Litre, the 3 year average from 2014-2017
    iii. Applies a price *increase* to 103 cents per Litre, the average of the projected prices from 2017 to 2042, based on +1.69% per year.

If the HP averages an annual COP of 2.41, there will be no investor profiles which return a positive NPV from a HP investment to displace HHO in NS in 2017 (Table 13). For the Investor 1 profile, the sensitivity testing revealed similar results for all input variations compared to Standard Assumptions. That is, households will yield a positive IRR and NPV by displacing their HHO with a HP; the lone exception is in the case that the HP underperforms to an average COP of 2.41, which results in 0% of the homes yielding a positive return (Table 13). Interestingly, the sensitivity tests reveal that even when reducing the price of heating oil to the two-year low-average between 2015-2017 ($0.90 /L), the majority of homes (71%) in the Investor 1 Profile, will still yield a positive return on their HP investment (Table 13). The sensitivity analysis reveals that the expected savings of a HP investment for an Investor 1 Profile is resilient to fluctuations in electricity and heating oil costs, but may be susceptible if the HP underperforms to a COP of 2.41 or lower.

The same does not apply to an Investor 2 profile, as most deviations in HP performance or fuel price fluctuations that do not favour the HP result in fewer homes yielding a positive IRR and NPV (Table 13). If electricity costs rise to $0.18/kWh while holding heating oil prices constant, the number of homes that can expect a positive NPV reduces to 0% compared to 15% under the Standard Assumptions. An oil price increase to $1.03 /L is the only change in model parameters that resulted in all Investor 2 profile homes having a positive NPV; whereas, only minimal improvement is achieved when electricity prices and HP performance move in favour of the HP (Table 13). The results are even more pronounced with the Investor 3 profile, which was developed to account for any potential *the Gap* related influences in HP investment in NS. For Investor 3 profile homes, nearly all sensitivity tests reveal that 0% of homes achieve net positive savings, with the exception of a heating oil price increase to $1.03/L and while holding all other Standard Assumptions constant (Table 13).

Table 13. Percentage of Homes in Study Yielding a Positive Return from a HP Investment to Displace HHO in 2017

Investor Profile	Standard Assumptions	1) HP COP		2) Electricity Cost ($/kWh)		3) Heating Oil Cost ($/L)		
		2.41	3.04	$0.14	$0.18	$0.90	$0.96	$1.03
1: Informed, low-cost	100%	0%	100%	100%	100%	71%	100%	100%
2: Informed, higher-cost	15%	0%	30%	21%	0%	15%	41%	100%
3: Informed, higher-cost	0%	0%	0%	0%	0%	0%	0%	21%

Chapter 5: Discussion

In NS, the transition from HHO to HP for residential home heating can reduce GHG emissions at the individual home scale and to the province cumulatively. Such an initiative could also contribute to achieving provincial, federal and global emission reductions targets today and into the future. It is broadly accepted globally that GHG emissions from the energy sector will have to be reduced to near or net-zero emissions, if society is to collectively mitigate climate change impacts (Kuramochi, 2017; CAT, 2016; Jacobson, et al., 2015). Furthermore, there is a growing body of literature emphasizing that electrification is the only attainable and clear path to net-zero emissions (Jacobsen, et al., 2015; Mahone, et al., 2015, Dennis, 2015; ENE, 2014).

Transitioning HHO to HP in combination with lower electricity generation emissions can support this transition towards net-zero emissions in the residential home heating sector. It should also be noted that among the many federal initiatives, key components of Canada's climate action strategy are focused on energy efficiency and fuel switching, with an emphasis on residential space heating, lighting, and electronics (Robins, 2017; PCF, 2016). This kind of technological transition supports the federal action plan of encouraging energy efficiency and fuel switching for residential space heating, along with reducing overall emissions.

5.1 Trends in Heat Pump Markets

The electrification of home heating is a trend noted in many regions across Canada and around the world. Globally, HP market penetration has been gaining in North America (Lapsa, Khowailed, Sikes, & Baxter, 2017), the European Union (EU) (EHPA, 2015) and several parts of Asia, especially China (Zhao, Gao, & Song, 2017). In the EU, HP sales have been increasing steadily since 2005, reaching almost 800,000 installations in 2014; with air-source heat pumps the most commonly installed system (EHPA, 2015). Certain EU countries are leading the way including France, Italy and Sweden, which each accounted for recent annual sales greater than 100,000 units, followed by Germany, Finland, and Spain, with annual sales exceeding 50,000 units (EHPA, 2015). The European Heat Pump Association (EHPA) estimates that more than 7.5 million heat pump units have been sold in the past 20 years across the EU, and have contributed to reducing an estimated 22.1 mega tonnes of CO_2e emissions (EHPA, 2015). In China, annual sales of air source heat pumps are in the range of 40 to 50 million, although the majority of this is for cooling purposes (Zhao, Gao, & Song, 2017). However, policy support for subsidies, efficiency standards and labels for HP's seem to be linked to the rapid growth in air-source water heaters and could suggest accelerating trends in the Chinese home heating sector especially in northern regions (Zhao et al, 2017).

Heat pumps in North America have gained market share but have struggled in northern regions with colder climates and less expensive alternatives such as natural gas, with the exception of areas with limited access to natural gas (Lapsa et al, 2017). In the United States, between 1988 and 2014, HPs market share has increased from 21% to 33% in the cooling market, and from 24% to 40% in the space heating market (Lapsa et al, 2017).

The number of residential HPs installed in Canada are primarily air-source, and have increased from approximately 415,000 in 2000 to about 733,000 in 2015 with the strongest uptake occurring in markets that have extensive HHO or electric baseboard heating (NEB, 2018). Not surprisingly, the HP market share in Canada has increased more rapidly since 2009: shipments increased by almost 300% in 2015 relative to 2009 shipments, while furnace shipments only grew by 10% relative to 2009 (Lapsa et al, 2017). Driving this increase is the shrinking price difference between traditional air-conditioning units and HPs, along with the fact that HPs also provide primary or secondary heating efficiently in cold climates. Homeowners find value in the HP when faced with a replacement situation (Lapsa et al, 2017).

5.1.1 Trends in Nova Scotia. There appears to be a transition happening in NS with respect to a transition away from HHO for primary residential home heating to greater use of HPs, but how far along the transition remains unclear as of early 2018. Most recent data from NRCan (2015) indicates approximately 5% of homes in NS use a HP for primary heating, whereas, a NSP customer survey in 2015 suggests it is closer to 11% (NSP, 2015; NRCan, 2015e). In 2017, the NS Climate Change website suggested that about 100,000 HPs had been installed in NS homes, of which, 80,000 were for primary heating (Climate Change NS, 2017b). If accurate, that would translate to approximately 20% of homes in NS using a HP for primary home heating (StatsCan, 2016). While the current home heating market share of HPs is unclear in NS, this research has illuminated some of the potential benefits of large-scale adoption of the technology across the province.

5.2 Implications for Emissions

The results of the model indicate that a transition to HPs can reduce annual GHG emissions in NS by up to ~140,000 tCO_2e (Table 7); these findings are consistent with other studies in regions similar to the NS climate - if paired with renewable energy generation (NEEP, 2017a; ENS, 2017d; Kelly, Fu, & Clinch, 2016; NEEP, 2014; Matley, 2013). However, the scale of potential emissions reductions in NS can be dampened if the emissions intensity of NSP does not decline as expected. Currently, the emissions intensity of NSP remains one of the highest in Canada (ECCC, 2015). And yet, findings indicate that operating a HP in NS in 2017, will reduce emissions relative to HHO, suggesting that the potential to reduce emissions could be ~140,000 tCO_2e (Table 7) annually for the Province. Recall, the model considers the maximum allowable

GHG emissions by NSP under the cap compliance periods until 2030 (Greenhouse Gas Emissions Regulations, 2009) and then considers the HIGH projection of NSP emissions intensity until 2042 (Figure 9). Therefore, the annual estimated GHG emission reduction potential of ~140,000 tCO_2e in 2017 is likely on the low end. If one considers the actual NSP emissions intensity of 2016, the GHG emission reduction potential increases to ~183,000 tCO_2e annually in 2017 for the Province, an increase of over 30% in reduction potential. These reductions in residential home heating emissions are particularly advantageous in NS because residential sector emissions represent a greater portion of total emissions, compared to the rest of Canada (NEB, 2016).

If the HP does not operate efficiently at an average annual COP of 2.87, the GHG emission reduction potential will reduce compared to the Standard Assumption estimates. The model demonstrated that if a HP averages an annual COP of 2.21, there will be no GHG emissions reductions achieved by displacing HHO in 2017 (Table 7). Although, while HP underperformance has the potential to reduce emissions reduction potential, the study considers a modest COP of 2.87. Modern testing at variable speeds and temperatures has shown that HP efficiency generally outperforms a COP of 2.87 (NEEP, 2017b), so it is not likely to be a major factor in the anticipated reduction potential.

5.3 Household Savings & Fuel Cost Variations

The analysis of individual level financial implications of a HP to displace HHO revealed that home heating operating costs would be reduced across all NS home segments considered, with larger savings achieved in homes with higher heating demand profiles, such as Segment 1 (Table 8). The efficiency advantages of HPs are expected to continue to support cost savings into the future, even if the cost of heating oil stays flat and electricity rates continue increasing along the trend noted over the past 10 years (Table 10). Even if the HP underperforms to a COP of 2.21 (the GHG emission break-even point in 2017), annual savings of almost $600 are still anticipated on average per home in 2017 (Table 9).

These findings are consistent with the research by Kelly et al. (2016), Letendre et al. (2014), and ENS (2017d). Kelly et al. (2016) tested the potential for air-source heat pumps in Ireland as an alternative to several sources of heating, including HHO. With access to data on individual home energy consumption, their study found that 99.89% of all households in Ireland would achieve an operating cost net savings by installing a HP compared to HHO. Letendre et al (2014) compared the cost savings of displacing HHO with HPs in the residential sector in Vermont, and reported average annual savings of $1350 (Letendre, Bentley, & Dunn, 2014). In addition, the ENS space heating cost comparisons suggest a HP will save money even compared to high efficient HHO furnaces (ENS, 2017d)

The actual operational cost savings for a HP will fluctuate over time, as a result of the variable differential between heating oil fuel costs and electricity. For example, it was found in the NEEP update report on the performance of cold climate HPs published in 2017 that the cost savings of displacing HHO with a HP had shrank considerably compared to the 2013 report, attributed primarily to a dramatic decrease in the cost of home heating oil (NEEP, 2017a). NS is certainly not immune to this sort of fuel-specific price fluctuation: in that same time frame, heating oil prices in Halifax dropped nearly 10% from $1.25Can per Litre in 2014 to $0.92Can per Litre at the end of 2017 (StatsCan, 2017). This price drop in heating oil resulted in annual operating cost savings in the study ranging from $1456 in 2014 heating oil prices to $851 in 2017 heating oil prices, while keeping the price of electricity constant at 2017 rates (Table 10).

With no domestic supply of heating oil in NS (NRCan, 2015f) volatile prices will likely continue into the foreseeable future. In addition, future carbon pricing will likely affect heating oil prices in NS and Canada, but the actual impact remains uncertain. The federal government announced in 2016 that a minimum nation-wide carbon price of $10 per tCO_2e by 2018 and $50 per tCO_2e by 2022 must be implemented, via a carbon tax, cap and trade program, or a hybrid approach (UNFCCC, 2017; PCF, 2016). NS has chosen to implement a cap and trade program beginning in January 2019, that will impact only three types of companies: petroleum product suppliers that handle 200 litres of fuel or more annually, electricity producers that emit 50,000 tCO2e or more annually, and natural gas distributers that produce 10,000 tCO2e or more per year (Climate Change NS, 2018). The potential impact on households is uncertain since, a) the government plans to give most of the allowances under the program for free, b) only 20 companies are expected to be affected, and c) the whole program is designed to "protect the pocketbooks of Nova Scotians" (Climate Change NS, 2018).

The cost of electricity on the other hand could potentially level out. With the recent major investments by NSP in local renewable generation sources, generation costs are less susceptible to foreign volatile fuel costs. There are several other factors that contribute to the cost of electricity, so only time will tell if these investments will reduce or at least limit rate increases for NSP consumers. The proposed new cap and trade system in NS recognizes the investments already made by NSP to lower emissions (Climate Change NS, 2018), so it is unlikely to increase costs to NSP with unforeseen emissions restrictions, and in turn pass those costs onto customers.

5.4 Potential Market for HPs According to Investor Profile

Three investor profiles were developed to represent a range of consumer heterogeneity with respect to their cost of borrowing and the potential presence of *the Gap* in NS. Within the Investor 1 profile (Informed, 3.15% interest & discount rate), all homes are expected to return a net positive savings on a HP investment (Table 9). These findings are consistent with Matley's (2013) report showing a levelized cost comparison[8] of various technologies, including HPs and HHO (Matley, 2013).

When borrowing costs and discount rates were increased as in the Investor 2 Profile (Informed, 7% interest & discount rate), the fraction of households with net positive savings are limited to Segment 1 homes, or approximately 15% of the current housing stock population. These results are broadly consistent with the findings of Kelly et al (2016), who applied a 5% interest rate and varying discount rates to residential households in Ireland, and considered the capital costs and running costs of the HP relative to the running costs of HHO. These researchers found that 62% of HHO households would return a net positive savings from installing a HP when applying a 5% discount rate, compared to just under 36% of homes at a 10% discount rate, and under 2% of homes when applying a 30% discount rate (Kelly, et al., 2016). The 30% discount rate was chosen by Kelly et al (2016) to include barriers related to *the Gap*.

These results highlight the significance of individual borrowing costs and discount rates on the anticipated financial return on a HP investment. We need not look further to the Investor 3 Profile (Not-informed, 7% interest rate, 10% discount rate), which resulted in 0% of NS homes recovering the investment of the HP. Clearly, if homes in NS experience issues related to *the Gap* – whether it be behavioural failures like limited attention or market failures such as

---

[8] reflects the capital and operating cost of each million BTU of heat provided over the course of the technologies' lifetime under different price forecast scenarios: HPs = \$30, Oil furnace = \$50

imperfect information on the benefits of HPs – this will cause the home to place less value on the future expected savings of the HP. Therefore, if the decision process of investors in NS choosing to install HPs is based solely on expected financial return, then the uptake of HPs in NS could be limited to the best-case scenario investor profiles, who are not impacted by *the Gap* related barriers.

It is unclear what the potential impact of *the Gap* is on investment behavior towards HPs in NS. Literature supports that there are several factors including some that are non-financial, that limit the uptake in seemingly economically beneficial investments in energy efficiency (Allcott, et al., 2014; Gillingham & Palmer, 2014; Jaffe & Stavins, 1994), including HPs (DEFRA, 2010). It was beyond the scope of this research to measure the presence of *the Gap* in NS or how influential it may be on investment behaviour; however, some observations can be made based on the findings that have emerged from this research.

5.5 The Energy Efficiency Gap in Nova Scotia

It is likely that the barriers related to *the Gap* (Figure 7) are at least somewhat present in the NS market for HPs. This study has identified three *Gap*-related barriers potentially influencing the behaviour of HP investment in NS, which include principal-agent issues, imperfect information, and uncertainty.

5.5.1 Principal-Agent Issues. Principal-agent issues are considered a form of market failure and arise when one party makes the decisions regarding energy use while another party pays or benefits from that decision (Gillingham & Palmer, 2014). A common example of the principal-agent issue is in the landlord-tenant situation: the landlord typically has all the decision power when it comes to investing in energy efficiency, whereas, the tenant will be the one who experiences the landlord’s decisions and potentially benefits or pays for it. There is empirical evidence showing this split-incentive structure does not encourage energy efficiency investment from the landlord or reduced energy consumption from the tenant in the residential sector (Davis, 2012; Gillingham et al., 2012), although the estimated consequences related to this market failure are relatively small (Gillingham & Palmer, 2014).

NS has a slightly lower home ownership rate (68.7%) compared to the rest of Atlantic Canada (73.8%) and all ten Canadian provinces (70.2%) (StatsCan, 2016), which suggests the split-incentive issue for improving energy efficiency could be more prevalent in NS households, as a greater proportion of the population is renting. Additionally, incentive programs from ENS for landlords are currently limited to encouraging LED lighting, water-saving showerheads and aerators, and insulating wrap for electric hot water tanks and pipes (ENS, 2018c). Therefore, for larger energy reduction technology transitions like conversions to HPs, there are no incentives available to landlords for improving the heating system of their rental properties.

The province of NS offers eligible landlords a small energy rebate on residential rental properties, provided certain conditions are met including that the landlord pays for the tenant home energy costs (Access NS, 2018). While this does not directly incentivise landlords to invest in energy efficiency, it may encourage landlords to include the energy costs in the lease when they otherwise would not. This could then encourage them to improve the efficiency of their buildings to reduce these costs.

5.5.2 Imperfect Information. When consumers have imperfect information about the benefits of investing in energy efficiency, they are less likely to do so (Gillingham & Palmer, 2014). Imperfect information is a form of market failure and requires considerable attention to reduce its influence on *the Gap*. Over half of the recommendations by the European Union

Energy Commission (EUEC) for improving the uptake of energy efficient investment (including HPs) relate to addressing this information gap (EUEC, 2017).

The average household's lack of knowledge regarding energy efficiency investment is one of the principle reasons for missed savings opportunities (Gillingham & Palmer, 2014). This knowledge gap is likely to be more pronounced in lower income households where the benefits would be highest (Gillingham & Palmer, 2014; Clinch & Healy, 2000). The median household income in NS in 2015 ($60,764) is well below the national average ($70,336) and the percentage of the population in the low-income bracket is also higher at 17.2% compared to the national average of 14.2% (StatsCan, 2016).

Information asymmetries between buyers and sellers in NS may also be contributing to slower uptake of HP investment, due to the lack of energy rating requirements in the NS residential real estate market. Sellers may have better information but are unable to express the benefits credibly to buyers, and homeowners are less likely to invest in energy efficiency measures if they are planning to sell because the monetary value of the improvements are rarely reflected in the resale price of the house (Gillingham & Palmer, 2014; Clinch & Healy, 2000). Unlike many jurisdictions in Europe, mandatory energy disclosure programs are not common in Canada for residential homes, despite building code standards that have gained momentum as an effective policy for reducing energy consumption in the residential sector (Palmer & Walls, 2017; Jacobsen & Kotchen, 2013; Aroonruengsawat, Auffhammer, & Sanstad, 2012). In contrast, countries such as Spain and Ireland have implemented mandatory energy performance ratings in their residential housing market. It has been shown that energy efficient homes get market price premiums compared to otherwise equivalent less-efficient homes, controlling for house type, size, age and location (Ayala, Galarraga, & Spadaro, 2016; Stanley, Lyons, R., & Lyons, S., 2015).

However, a recent pilot project in NS was announced that will potentially help overcome information asymmetries between buyers and sellers in NS. In collaboration with NRCan, ENS, the NS Realtors Association and ViewPoint Realty, a private web-based aggregator of real estate information across the province, the pilot project gives homeowners in NS the option to include EnerGuide information in their public listing (ENS, 2018b). The EnerGuide rating system provides home sellers with a tool to measure and report their home's energy performance and potential home buyers with a consistent basis upon which to compare the potential costs of the homes they are considering (NRCan, 2018). This could potentially lead to market premiums paid for homes with higher energy ratings, at it has been shown to in Ireland and Spain (Ayala, et al., 2016; Stanley, et al., 2015). This new option might encourage NS homeowners to invest in HPs to improve the EnerGuide rating of their home. However, as the program is voluntary, there may not be enough participants to see any real benefits.

5.5.3 Uncertainty. A common uncertainty experienced in energy efficiency investments when presented with a fuel choice like heating oil or electricity is the future prices of these fuels. Consumers may require an increase of four or five times the expected rate of return to make an investment if faced with uncertainty (Gillingham & Palmer, 2014; Hassett & Metcalf, 1993). However, Baker (2012) suggests that the earlier findings of Hassett and Metcalf (1993) do not apply when there are multiple options with different efficiencies (Baker, 2012). Investments in HPs can involve high impact renovations; the irreversibility of these investments can heighten the sense of risk and uncertainty (Gillingham& Palmer 2014). Risk and uncertainty is commonly attributed to why firms do not follow up on energy audit recommendations despite quick payback periods (Anderson & Newell, 2004).

As previously noted, the cost of heating oil in NS and neighbouring regions has fluctuated in recent years and has dramatically shrunk the expected savings of a HP investment to displace HHO (StatsCan, 2017; NEEP, 2017a). With no domestic supply of heating oil in NS (NRCan, 2015f), and carbon pricing on the horizon in NS and Canada (Climate Change NS, 2018; UNFCCC, 2017), volatile prices will likely continue into the foreseeable future and contribute to uncertainty surrounding any investment involving HHO. In this case, the volatility of heating oil prices may influence consumer behaviour in favour of a HP. On the other hand, if consumers are not confident that NSP will be able to maintain stable electricity rates while transitioning to renewable energy generation to meet emissions cap compliance requirements, then the anticipated cost of electricity will be uncertain and might hinder HP investment behaviour.

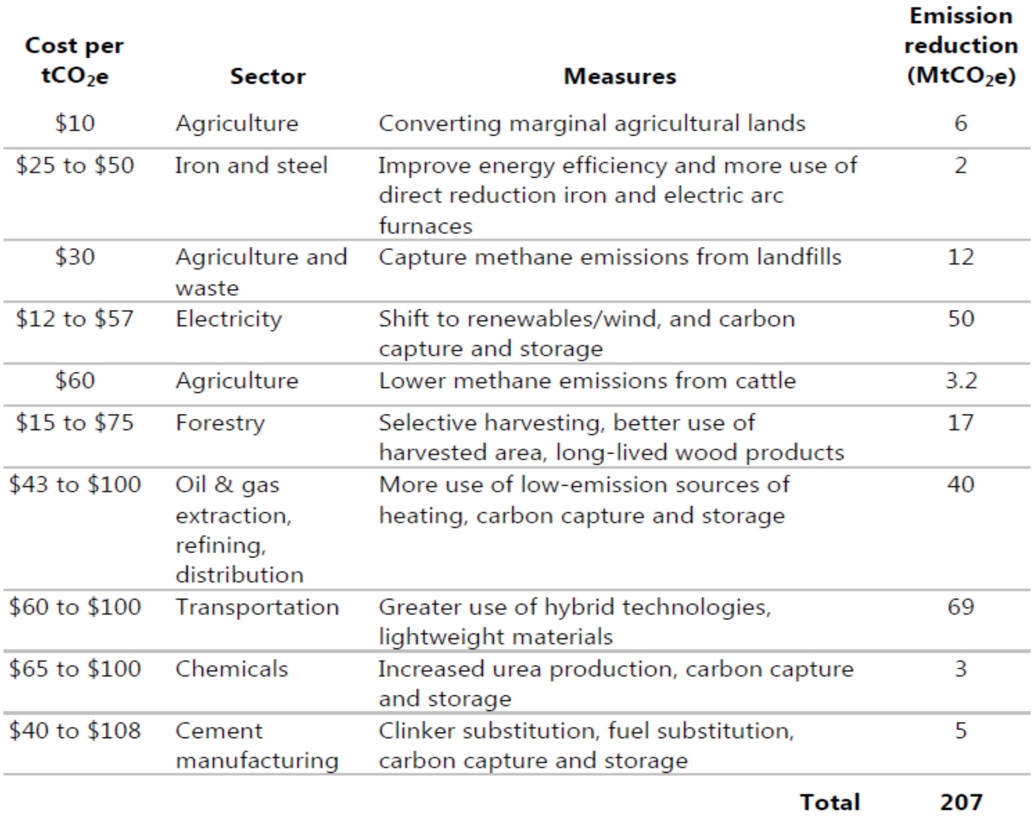
5.5.4 Overcoming *the Gap*. It is important to identify the specific market or behavioural failures affecting the uptake of HPs in NS if a policy solution to overcome them is to be developed (Gillingham & Palmer, 2014). Further research is required to determine which specific market or behavioural failures are impacting the NS marketplace, but is beyond the scope of this study. The most common policy tools for overcoming *the Gap* are information strategies combined with economic incentives, typically some kind of rebate (Palmer & Walls, 2017; Gillingham & Palmer, 2014; Allcott & Greenstone, 2012; Clinch & Healy, 2000). Currently, several government agencies, organizations and private companies are doing some form of both in NS. NSP has been advertising through multiple platforms the benefits of HPs and their HP financing program; the NS DOE is expanding ENS programs to support further HP adoption through federal funding; municipalities in NS are offering additional local financing programs for HPs; and several local HP contractors are promoting the benefits of HPs to consumers. It is unclear at this time how effective these information strategies provided by NSP and local HP contractors are in NS in reducing the imperfect information market failure, considering these companies benefit directly from HP investment, which could lead to uncertainty for the consumer.

5.6 Incentivising the Transition to HPs from HHO in NS

During the time of writing, the Province of NS expanded ENS's mandate to include incentive programming for homes on HHO via the funding received from the federal LCEF (Berman, 2017; ENS, 2017b). ENS has limited the programs to mini-split ductless air-source heat pumps; there are no incentives for central ducted, air-to-water and geothermal systems, or the rest of the HEA program (ENS, 2017c).

The results of this study have demonstrated that investor profiles with higher borrowing costs or discount rates are not anticipated to return a net positive savings on their HP investment. Therefore, it seems logical that a financial rebate to homes on HHO may encourage more HP adoption and associated GHG emission reductions. However, does it actually make sense for the Province - considering the LCEF can be used towards any low carbon initiative – to direct funds toward incentivizing the uptake of HPs?

5.6.1 Cost of Abating Emissions. It is widely accepted that incentives are necessary to change behaviour of individuals and businesses, but incentive structures can be complex and have very different costs and intended outcomes (Gerarden et al, 2015). Abatement costs provide a measuring tool for policy makers to compare the cost-benefits (\$ per tCO_2e) of emissions reducing incentive programs. Ideally, incentive programs achieve the greatest amount of emissions reductions at the least economic cost (PBO, 2016; NRTEE, 2009). It does not necessarily mean the lowest abatement costs are always the best option; the opportunity to reduce emissions in each major sector varies from available technologies and economic constraints (PBO, 2016). The Office of the Canadian federal Parliamentary Budget Officer (PBO) provides a discussion of potential abatement costs across Canadian sectors with currently available technologies (Figure 9). The costs provided in Figure 9 are intended as general guidelines for emissions pricing, if Canada is to substantially reduce emissions and potentially achieve emission reduction targets (PBO, 2016).



Cost per tCO_2e	**Sector**	**Measures**	**Emission reduction ($MtCO_2e$)**
$10	Agriculture	Converting marginal agricultural lands	6
$25 to $50	Iron and steel	Improve energy efficiency and more use of direct reduction iron and electric arc furnaces	2
$30	Agriculture and waste	Capture methane emissions from landfills	12
$12 to $57	Electricity	Shift to renewables/wind, and carbon capture and storage	50
$60	Agriculture	Lower methane emissions from cattle	3.2
$15 to $75	Forestry	Selective harvesting, better use of harvested area, long-lived wood products	17
$43 to $100	Oil & gas extraction, refining, distribution	More use of low-emission sources of heating, carbon capture and storage	40
$60 to $100	Transportation	Greater use of hybrid technologies, lightweight materials	69
$65 to $100	Chemicals	Increased urea production, carbon capture and storage	3
$40 to $108	Cement manufacturing	Clinker substitution, fuel substitution, carbon capture and storage	5
		Total	**207**

Figure 9. Abatement measures across sectors in Canada (PBO, 2016)

The abatements costs range from $10 to $108 per tCO_2e, but most sectors fall in the range of $30 to $100 per tCO_2e of GHG emissions abated (Figure 9). These estimates of emissions abatement costs differ from Canada's National Round Table on the Environment and the Economy (NRTEE) 2009 report. The NRTEE suggested that economy-wide emissions pricing in

Canada would need to rise to \$100 per tCO_2e by 2020 and upward of \$300 per tCO_2e by 2050, to drive the behavioural changes and technological deployment potentially necessary to achieve deep reductions and achieve targets (NRTEE, 2009).

The PBO guidelines do not offer specifics for programs designed at residential home heating, which are often more difficult to estimate than other sectors because of the potential presence of *the Gap* and its influence on individual investment decisions. However, high level results from a Canadian residential energy retrofit program fall within PBO ranges. A retrofit program funded by the federal government between 2007 and 2010, led to 640,000 homes participating at a cost of approximately \$1500 per home. From the government's perspective, the cost per tCO_2e of emissions abated was just less than \$100 in natural gas heated homes and about \$50 in homes heating with HHO (PBO, 2016). Upon completion of this work, there were no data available to compare the abatement costs of residential heating incentive programs for HPs specific for NS.

Chapter 6: Conclusion and Recommendations

The intent of this research was to: a) assess the performance of cold climate HPs and associated GHG emissions relative to HHO in a carbon-intensive electricity-generating jurisdiction; and b) determine if a HP investment to displace HHO would return net positive savings to the individual household. Using NS as the basis for the analysis, it has been shown that displacing HHO with HPs is expected to reduce residential home heating emissions for all homes and cumulatively for the province. It has also been shown that HPs pair well with an improving power grid; as NSP continues to lower its electricity generation emissions intensity with increased renewable energy sources, the reduction potential of the HP becomes even greater.

Meaningful emissions reduction requires efforts on all scales, and energy efficiency is a key component to reducing emissions and mitigating impacts (IEA, 2016; IPCC, 2014). The majority of residential emissions in Canada are from space heating (NRCan, 2015d); and in the NS context, it represents a greater proportion of total emissions (NEB, 2016), so the reduction opportunity is greater. Encouraging the adoption of HPs aligns with provincial, federal, and even global initiatives in encouraging energy efficiency, and also creating a long-term path to substantial emissions reductions. That is, if the transition to HPs is combined with increased renewable generation, the home heating sector in NS could eventually achieve net-zero emissions. The transition to HPs may also increase energy security to the provincial heating sector, as it will reduce reliance on foreign heating oil, since the province has no domestic supply (NRCan, 2015f).

Although it has been shown that households can expect operating cost savings with a HP relative to HHO in all home segments, the net savings after including all real costs of the investment to the individual, is highly variable and not always positive. The expected net savings is variable due largely to differences in homeowner costs of borrowing and the value they place on the expected future savings – which is potentially influenced by factors outlined in *the Gap*. *The Gap* related barriers are potentially present in NS and as such are likely to cause individuals to place higher discount rates on future expected savings of the HP investment. When individuals experience higher discount rates, the economic case for investing in a HP is not as strong, which may limit the uptake of HPs to only households who are not hindered by issues related to *the Gap* and have access to relatively lower borrowing costs. For these reasons, and for the GHG emission implications, the province may want to consider policies to incentive the transition to HPs in NS.

6.1 Recommendations

6.1.1 Incentivize the Transition. Since the transition from HHO to HPs for residential home heating has been shown to reduce GHG emissions, it may make sense for NS to incentivize this transition, as it aligns with provincial and federal goals of transitioning to a low-carbon economy. The case for incentivising the HP transition becomes even stronger when considering all the potential real costs experienced by the individual homeowner. In the cases where individuals have higher borrowing costs or discount rates, this study has shown that the nets savings from a HP investment could be negative, and therefore an incentive to reduce the upfront capital costs could potentially mitigate the risk. Of course, much would then depend on the relative GHG emission reductions that could be achieved for a given incentive program compared to other possible government initiatives, and such an analysis is warranted and should be undertaken.

6.1.2 Review the Incentive Program. It is important to constantly review and improve incentive programs to ensure they are addressing specific market and behavioural failures

(Gillingham & Palmer, 2014). Since ENS just started the rebate program for HHO homes, there are no results available to review. Additional research is required to understand the impacts of ENS incentive programs on consumer behaviour in NS and to ensure both market and behavioural failures are being addressed. Also, considering the new program is funded by the federal LCEF, it would be useful if the review of the program included a GHG emission abatement cost,[9] so the province could compare the programs cost-effectiveness in reducing emissions with other emission reduction initiatives.

6.1.3 Complement Incentive Program with Information Provision. Regardless of the potential benefits of an incentive program, there are also potential benefits to be had from public education efforts to help overcome *the Gap*, a common strategy recommended in literature that explores the impacts of and responses to *the Gap* (Palmer & Walls, 2017; Gillingham & Palmer, 2014; Allcott & Greenstone, 2012; Clinch & Healy, 2000). ENS could potentially benefit from joint marketing campaigns with NSP to help disseminate information and increase consumer awareness of both the private and collective benefits of a conversion to HPs for home heating. The best policies for encouraging investment in energy efficiency identify the specific market and behavioural failures and then tailor a policy to overcome them (Gillingham & Palmer, 2014). Further research on *the Gap* and how it relates to the NS context could be beneficial in policy design for HPs and other energy efficiency measures.

6.1.4 Improve HP Market Data in NS. A better understanding of the proportion of homes in NS which have already installed a HP and the number of homes still heating with HHO would also be beneficial for overall direction in policy design. Perhaps HP technology is already widely regarded as a superior technology to HHO in NS, and the transition will happen

---

[9] Recall, ENS programs are funded by the utility – NSP – and are measured in cost per kWh of electricity saved

regardless of the provision of additional education or incentive programs. This information would be useful to NS policy makers in designing the incentive. For example, if the average household in NS already recognizes the benefits of HPs and would choose to install one anyway, then the incentive could be designed towards encouraging the purchase of superior models with higher efficiencies. Additionally, the incentive could be designed to encourage not only a HP investment, but also investment in technologies that pair well with HPs such as electric thermal storage and solar PV – this bundling strategy is already commonly used in ENS programming.

6.1.5 Improve Household Energy Consumption Data in NS, Canada. A better resource for Canadian residential energy consumption data would allow for more accurate energy modelling and could translate to better information to policy makers. Some countries require mandatory energy performance ratings in the residential market, and if Canada implemented this, a host of benefits could potentially be realized including better household energy data. Mandatory energy labelling could help remove the imperfect information issue between buyers and sellers and encourage homeowners to invest in energy efficiency (Gillingham & Palmer, 2014; Clinch & Healy, 2000), especially since it has been shown to help recapture the investment cost in the resale price (Ayala, et al., 2016; Stanley, et al., 2015). Only time will tell if the new pilot project in NS, which allows homeowners to include EnerGuide ratings in real estate listings, will lead to market premiums paid for more efficient homes, and encourage investment in energy efficiency.

6.1.6 Summary of Recommendations to Accelerate HP adoption in NS. Generally, NS should increase or continue to support the following seven key market strategies, which collectively, could accelerate the adoption of HPs in NS:

- Increase consumer education and awareness of the benefits of HPs.

- Reduce upfront costs of HP systems through robust and aligned incentive programs. Continually monitor and update programs to ensure they are addressing correct market or behavioural failures.
- Continue support from federal, provincial and local policy makers to expand support for HPs and reduce consumption of fossil fuels.
- Ensure the promotion of climate-appropriate HPs which have been tested using the latest performance metrics – at variable capacities and temperatures. This can include constant review and updating of eligible HPs for ENS incentive programs.
- Promote technologies that pair well with HPs such as advanced control technologies, electric thermal storage and solar PV.
- Develop more accurate tools to predict energy, cost and GHG emission reductions associated with HPs through collection and analysis of real world performance data – Canada and NS can do much better with this.
- Monitor the new pilot project that allows home sellers in NS to include the EnerGuide rating in their real estate listing, to see if energy efficient homes attract higher market premiums. If this can be shown as it has in other countries, NS should consider promoting the program and potentially making it mandatory.

These recommendations are consistent with typical policy measures to encourage investment in HPs and overcome *the Gap*, and are likely good strategies for NS. By following some or all of the these strategies, the province can anticipate an increase in HP investment and benefit from the associated GHG emission reductions.

Bibliography

Abreu, C. (2013). *Electricity and nova scotia's future: hurdles and opportunities.* Halifax, NS: Ecological Action Centre. Retrieved from https://ecologyaction.ca/files/images-documents/file/Energy/ElectricityAndNSFuture_LoRes.pdf

Access NS. (2018). *Landlords*. Retrieved from https://novascotia.ca/sns/access/business/your-energy-rebate/landlords.asp#faq14918

Adams, M., Wheeler, D., & Woolston, D. (2011). A participatory approach to sustainable energy strategy development in a carbon-intensive jursidition: the case of nova scotia. *Energy Policy, 39*(5), 2550-2559. Retrieved from https://www.sciencedirect.com/science/article/pii/S0301421511001029?via%3Dihub

Alcamo, J. (2008). *Environmental futures: the practice of environmental scenario analysis.* Amsterdam, The Netherlands: Elsevier.

Allcott, H., & Greenstone, M. (2012). Is there an energy efficiency gap. *Journal of Economic Perspectives, 26*(1), 3-28.

Allcott, H., Mullainathan, S., & Taubinsky, D. (2014). Energy policy with externalities and internalities. *Journal of Public Economics, 112*, 72-88.

Anderson, S., & Newell, R. (2004). Information programs for technology adoption: the case of energy-efficiency audits. *Resource and Energy Economics, 26*(1), 27-50.

Aroonruengsawat, A., Auffhammer, M., & Sanstad, A. (2012). The impact of state-level building codes on residential energy consumption. *Energy Journal, 33*(1), 31-52.

Arteconi, A., Hewitt, N., & Polonara, F. (2012). State of the art thermal storage for demand-side management. *Applied Energy, 93*, 371-389.

Arteconi, A., Hewitt, N., & Polonara, F. (2013). Domestic demand-side management (dsm): role of heat pumps and thermal energy storage (tes) systems. *Applied Thermal Energy, 51*, 155-165.

Atlantica Centre for Energy. (2015). *Natural gas supply and demand report new brunswick and nova soctia 2015-2025.* Retrieved from http://www.atlanticaenergy.org/uploads/file/natural_gas_supply_demand_report.pdf

Ayala, A., Galarraga, I., & Spadaro, J. (2016). The price of energy efficiency in the spanish housing market. *Energy Policy, 94*, 16-24.

Baker, E. (2012). Option value and the diffusion of energy efficient products. *Energy Journal, 33*(4), 49-59.

Bas, E. (2013). A robust approach to the decision rules of npv and irr for simple projects. *Applied Mathematics and Computation, 219*(11), 5901-5908. Retrieved from https://www.sciencedirect.com/science/article/abs/pii/S0096300312013070

Berkovec, J., Hausman, J., & Rust, J. (1983). *Heating system and appliance choice.* MIT Energy Laboratory: Cambridge, MA.

Berman, P. (2017, June 16). Efficiency nova scotia expands programs to homes heated by oil and wood. *CBC News*. Retrieved from http://www.cbc.ca/news/canada/nova-scotia/efficiency-nova-scotia-oil-wood-heat-green-energy-investment-1.4164584

Broin, E., Mata, E., & Nassen, J. (2015). Quantification of the energy efficiency gap in the swedish residential sector. *Energy Efficiency, 8*, 975-993.

Budale, B. (2014, January 10). High demand causes furnace oil shortage. *Chronicle Herald*. Retrieved from http://thechronicleherald.ca/business/1178858-high-demand-causes-furnace-oil-shortage

CAT. (2016). *The ten most important short-term steps to limit warming to 1.5°C.* Climate Action Tracker. Retrieved from http://climateactiontracker.org/publications/publication/266/The-ten-most-important-short-term-steps-to-limit-warming-to-1.5C.html

CAT. (2017a). *Canada*. Retrieved from http://climateactiontracker.org/countries/canada

CAT. (2017b). *Improvement in warming outlook as India and China move ahead, but paris agreement gap still looms large*. Retrieved from https://climateactiontracker.org/documents/61/CAT_2017-11-15_ImprovementInWarmingOutlook_BriefingPaper.pdf

Chau, K., Chou, S., & Yang, W. (2010). Advances in heat pump systems: a review. *Applied Energy, 87*(12), 3611-3624. Retrieved from https://www.sciencedirect.com/science/article/pii/S030626191000228X

Chronicle Herald. (2017, December 15). N.S. energy efficiency program gets funding boost. *Chronicle Herald*. Retrieved from http://thechronicleherald.ca/novascotia/1530054-n.s.-energy-efficiency-program-gets-funding-boost

Climate Change NS. (2017a). *Adapting to climate change*. Retrieved from https://climatechange.novascotia.ca/adapting-to-climate-change/impacts

Climate Change NS. (2017b). *Nova scotia's action on climate change*. Retrieved from https://climatechange.novascotia.ca/action-on-climate-change

Climate Change NS. (2017c). *Taking action on climate change*. Retrieved from https://climatechange.novascotia.ca/sites/default/files/Climate-Change_English.pdf

Climate Change NS. (2018). *Nova scotia's proposed cap and trade program*. Retrieved from https://climatechange.novascotia.ca/proposed-cap-and-trade-program

Clinch, J. P., & Healy, J. D. (1999). Domestic energy efficiency in ireland: correcting market failure. *Energy Policy, 28*, 1-8.

Clinch, J., & Healy, J. (2000). Domestic energy efficiency in ireland: correcting market failure. *Energy Policy, 28*, 1-8.

CMHC. (2013). *Long-term household growth projections - 2013 update.* Ottawa, ON: Canadian Mortgage and Housing Corporation.

Cook, J., Oreskes, N., Doran, P., Anderegg, W., Verheggen, B., Maibach, E., . . . Rice, K. (2016, April 13). Consensus on consensus: a sythesis of consensus estimates on human-caused global warming. *Environmental Research Letters, 11*(4). Retrieved from http://iopscience.iop.org/article/10.1088/1748-9326/11/4/048002

Costello, W. (2017). Why natural gas has an uncertain future. *The Electricity Journal, 30*, 18-22.

Daborn, G. R. (2016). *Nova scotia tidal research summary report.* Offshore Energy Research Association. Retrieved from http://www.oera.ca/wp-content/uploads/2016/05/Researching-Tidal-Energy-FINAL-May-2016.pdf

DeCanio, S. J., & Fremstad, A. (2011). Economic feasibility of the path to zero net carbon emissions. *Energy Policy*, 1144-1153.

DEFRA. (2010). *Behavioural economics & energy using products: scoping research on discounting behaviour and consumer reference points.* London: Department of Environment, Food and Rural Affairs. Retrieved from file:///C:/Users/gilm023/Downloads/EV0701_9169_FRP.pdf

DellaVigna, S. (2009). Psychology and economics: evidence from the field. *Journal of Economic Literature, 47*(2), 315-372.

Dennis, K. (2015). Environmentally beneficial electrification: electricity as the end-use option. *Electricity Journal, 28*(9), 100-112.

Dennis, K., Colburn, K., & Lazar, J. (2016). Environmentally beneficial electrification: the dawn of emissions efficiency. *The Electricity Journal, 29*, 52-58.

Dubin, J. (1982). *Econometric theory and estimation of the demand for consumer durable goods and their utilisation: appliance choice and the demand for electricity.* Cambridge, MA: MIT Energy Laboratory.

ECCC. (2015). *National and provincial territorial greenhouse gas emission tables*. Retrieved from http://data.ec.gc.ca/data/substances/monitor/national-and-provincial-territorial-greenhouse-gas-emission-tables/

ECCC. (2016). *Canada's mid-century long-term low-greenhouse gas development strategy.* Ottawa, ON: Environment and Climate Change Canada. Retrieved from http://unfccc.int/files/focus/long-term_strategies/application/pdf/canadas_mid-century_long-term_strategy.pdf

ECCC. (2017a, April). *Canadian environment sustainability indicators: greenhouse gas emissions.* Ottawa, ON: Enviroment and Climate Change Canada. Retrieved from Environment and Climate Change Canada: https://www.canada.ca/content/dam/eccc/documents/pdf/cesindicators/greenhouse-gas-emissions/greenhouse-gas-emissions-en.pdf

ECCC. (2017b, June 15). Low carbon economy fund to reduce greenhouse gas emissions and generate clean growth. *Environment and Climate Change Canada*. Retrieved from https://www.canada.ca/en/environment-climate-change/news/2017/06/low_carbon_economyfundtoreducegreenhousegasemissionsandgeneratec.html

ECCC. (2017c). *Overview of 2015 reported emissions.* Ottawa, ON: Enviornment and Climate Change Canada. Retrieved from http://www.ec.gc.ca/ges-ghg/82BA1E22-9653-45F1-8EC2-9BF8A2151555/ECCC_GHGRP_OverviewOfReported2015Emissions.pdf

ECCC. (2018a). *Annex 13: national inventory report 1990-2016: greenhouse gas sources and sink in canada.* Ottawa, ON: Environment and Climate Change Canada. Retrieved from http://donnees.ec.gc.ca/data/substances/monitor/national-and-provincial-territorial-greenhouse-gas-emission-tables/E-Tables-Electricity-Canada-Provinces-Territories/?lang=en

ECCC. (2018b). *National inventory report 1990-2016: greenhouse gas sources and sink in canada.* Ottawa, ON: Environment and Climate Change Canada. Retrieved from https://www.canada.ca/content/dam/eccc/documents/pdf/climate-change/emissions-inventories-reporting/nir-executive-summary/National%20Inventory%20Report%20Executive%20Summary%202018.pdf

EHPA. (2015). *European heat pump market and statistics executive summary 2015.* European Heat Pump Association. Retrieved from http://www.ehpa.org/fileadmin/red/07._Market_Data/2014/EHPA_European_Heat_Pump_Market_and_Statistics_Report_2015_-_executive_Summary.pdf

Emera. (2017). *Maritime link*. Retrieved from http://www.emeranl.com/en/home/themaritimelink/overview.aspx

ENE. (2014). *EnergyVision a pathway to a modern, sustainable, low carbon economic and environmental future.* Rockport, ME: Environment Northeast, Inc. Retrieved from https://www.issuelab.org/resource/energyvision-a-pathway-to-a-modern-sustainable-low-carbon-economic-and-environmental-future.html

Engineering Toolbox. (2017). *Fuels - higher calorific values*. Retrieved from https://www.engineeringtoolbox.com/fuels-higher-calorific-values-d_169.html

ENS. (2016). *Existing residential program 2016 dsm evaluation final report.* Halifax, NS: Efficiency Nova Scotia.

ENS. (2017a). *About efficiency nova scotia*. Retrieved from https://www.efficiencyns.ca/about-us/

ENS. (2017b, June 16). Government announces more support for energy efficiency. *Efficiency Nova Scotia*. Retrieved from https://www.efficiencyns.ca/news/government-announces-support-energy-efficiency/

ENS. (2017c). *Green heat*. Retrieved from https://www.efficiencyns.ca/service/home-heating/

ENS. (2017d). *Heating comparisons*. Retrieved from https://www.efficiencyns.ca/guide/heating-comparisons/

ENS. (2017e). *Solar air heating*. Retrieved from https://www.efficiencyns.ca/guide/solar-fact-guide/

ENS. (2017f). *The facts about heat pumps*. Retrieved 12 10, 2017, from https://www.efficiencyns.ca/guide/facts-about-heat-pumps/

ENS. (2018a). *Homeowner's guide to heating with electricity*. Retrieved from https://www.efficiencyns.ca/wp-content/uploads/2016/11/Homeowners-Guide-to-Heating-with-Electricity.pdf

ENS. (2018b, 06 16). New pilot project helps increase efficiency, comfort and value of homes. *Efficiency Nova Scotia*. Retrieved from https://www.efficiencyns.ca/news/new-pilot-project-helps-increase-efficiency-comfort-value-homes/

ENS. (2018c). *Rental properties & condo upgrades*. Retrieved from https://www.efficiencyns.ca/service/rental-properties-condo-upgrades/

Environment Canada. (2013). *National invetory report [Table A6-4: emission factors for refined petroleum products]*. Environment Canada.

Environment Canada. (2015). *Final screening assessment petroleum sector stream approach fuel oil no. 2.* Environment Canada. Retrieved from http://www.ec.gc.ca/ese-ees/CA593523-4175-4FC0-8546-A8A9482FF242/FSAR_PSSA-S3_FO%20No.%202_EN.pdf

Environment Canada. (2017). *Station results- 1981-2010 climate normals and averages*. Retrieved from http://climate.weather.gc.ca/climate_normals/station_select_1981_2010_e.html?searchType=stnProv&lstProvince=NS

Environment Canada. (n.d.). *Fuel Oil No. 2*. Retrieved from http://www.etc-cte.ec.gc.ca/databases/Oilproperties/pdf/WEB_Fuel_Oil_No._2.pdf

Environment NS. (2009). *Toward a greener future nova scotia's climate change action plan.* Halifax, NS: Environment Nova Scotia. Retrieved from https://climatechange.novascotia.ca/sites/default/files/uploads/ccap.pdf

Environment NS. (2017). *Domestic oil spills*. Retrieved from https://novascotia.ca/nse/contaminatedsites/domestic.asp

Environmental Goals and Sustainable Prosperity Act. (2007). c. 7, s. 1. Retrieved from http://nslegislature.ca/legc/statutes/environmental%20goals%20and%20sustainable%20prosperity.pdf

EPA. (2016). *Global Greenhouse Gas Emissions Data.* US Environmental Protection Agency. Retrieved from Environmental Protection Agency: https://www3.epa.gov/climatechange/ghgemissions/global.html

EPA. (2017). *Greenhouse gas equivalencies calculator*. Retrieved from https://www.epa.gov/energy/greenhouse-gas-equivalencies-calculator

EUEC. (2017). *Energy Efficiency*. Retrieved from https://ec.europa.eu/energy/en/topics/energy-efficiency

Fitz-Morris, J., & Tunney, C. (2015, November 23). Justin trudeau promises 'canadian appraoch' to climate change. *CBC News*. Retrieved from http://www.cbc.ca/news/politics/trudeau-first-ministers-meet-climate-change-1.3331290

FORCE. (2016). *Annual report 2016.* Fundy Ocean Research Centre. Retrieved from http://fundyforce.ca/wp-content/uploads/2012/05/FORCE-Annual-Report-2016final.pdf

Galarraga, I., Abadie, L., & Kallbekken, S. (2016). Designing incentive schemes for promoting energy-efficient appliances: a new methodology and a case study for spain. *Energy Policy, 90*, 24-36.

Gao, Y., Gao, X., & Zhang, X. (2017). The 2°C global temperature target and the evolution of the long-term goal of addressing climate change -- from the united nations framework convention on climate change. *Engineering, 3*, 272-278. Retrieved from https://www.sciencedirect.com/science/article/pii/S2095809917303077

Gerarden, T., Newell, R., Stavins, R., & Stowe, R. (2015). *An assessment of the energy-efficiency gap and its implications for climate change policy. Discussion Paper ES 203-3.* Cambridge, MA: Harvard Project on Climate Agreements.

Ghosh, I. (2016, May 23). Fuel switching: an essential step towards a decarbonized future. *CleanTechnica*. Retrieved from https://cleantechnica.com/2016/05/23/fuel-switching-essential-step-towards-decarbonized-future/

Gillingham, K., & Palmer, K. (2014). Bridging the energy efficiency gap: policy insights from economic theory and empirical evidence. *Review of Enviornmental Economics and Policy, 8*(1), 18-38.

Giraudet, L., & Houde, S. (2015). *Double moral hazard and the energy efficiency gap.* Retrieved from https://www.tse-fr.eu/sites/default/files/TSE/documents/conf/energy_climat/Papers/giraudet.pdf

Goett, A. (1978). *Appliance fuel choice: an applicaiton of discrete mulitvariate analysis.* Davis, CA: California Energy Commission.

Goett, A. (1983). *Household appliance choice: revision of reeps behavioral models.* Palo Alto, CA: Electric Power Research Institute.

Goett, A., & McFadden, D. (1982). *Residential end-use energy planning system (reeps).* Palo Alto, CA: Electric Power Research Institute.

Government of Canada. (2010). *A Climate Change Plan for the Purposes of the Kyoto Protocol Implementation Act*. Retrieved from http://www.climatechange.gc.ca/default.asp?lang=En&n=4D57AF05-1

Greenhouse Gas Emissions Regulations. (2009). c.[1], s.[112]. Retrieved from https://www.novascotia.ca/JUST/REGULATIONS/regs/envgreenhouse.htm

Guoyuan, M., Qinhu, C., & Yi, J. (2003). Experimental investigation of air-source heat pump for cold regions. *International Journal of Refrigeration, 26*(1), 12-18. Retrieved from https://www.sciencedirect.com/science/article/pii/S014070070200083X

Hassett, K., & Metcalf, G. (1993). Energy conservation investment: do consumers discount the future correctly? *Energy Policy, 21*(6), 710-716.

Helin, T., Sokka, L., Soimakallio, S., Pingoud, K., & Pajula, T. (2013). Approaches for inclusion of forest carbon cycle in life cycle assessment - a review. *GCB Bioenergy, 5*(5), 475-486. Retrieved from https://onlinelibrary.wiley.com/doi/full/10.1111/gcbb.12016

Henman, I. (2014, March 29). Ductless vs ducted heat pumps -- what's the difference? *Sunshine Renewable Energy*. Retrieved from Sunshine Renewable Energy: https://www.sunshinerenewables.ca/ductless-vs-ducted-heat-pumps-whats-difference/

Heritage Gas. (2018). *Rates*. Retrieved from http://www.heritagegas.com/for-business/paying-for-natural-gas/rates/

Hermelink, A., & de Jager, D. (2015). *Evaluating our future: the crucial role of discount rates in european commission energy system modelling.* Stockholm, Sweden: The European Council for an Energy Efficient Economy. Retrieved from https://www.eceee.org/static/media/uploads/site-2/policy-areas/discount-rates/evaluating-our-future-report.pdf

Hughes, L. (2012). A generic framework for the description and analysis of eneryg security in an energy system. *Energy Policy*, 221-231.

Hughes, L. (2016). *Electric vehicles in nova scotia: an examination of availablility, affordability, and acceptability issues.* Halifax: NSP.

IEA. (2011). *25 energy efficiency policy reccomendations.* International Energy Agency. Retrieved from http://www.iea.org/publications/freepublications/publication/25recom_2011.pdf

IEA. (2014). *Energy efficiency market report.* Paris: International Energy Agency.

IEA. (2016). *Energy efficiency market report 2016.* Paris: International Energy Agency.

IEA. (2017). *CO2 emissions from fuel combusiton highlights.* International Energy Agency. Retrieved from https://www.iea.org/publications/freepublications/publication/CO2EmissionsfromFuelCombustionHighlights2017.pdf

Investopedia. (2017). *Internal rate of return - irr*. Retrieved from https://www.investopedia.com/terms/i/irr.asp

IPCC. (2006). *2006 ipcc guidelines for national greenhouse gas inventories.* Geneva, Switzerland: Intergovernmental Panel on Climate Change. Retrieved from http://www.ipccnggip.iges.or.jp/public/2006gl/index.html

IPCC. (2012). *Fourth assessment report.* New York, NY: Intergovernmental Panel on Climate Change. Retrieved from http://www.ipcc.ch/pdf/assessment-report/ar4/wg1/ar4-wg1-chapter2.pdf

IPCC. (2014). *Climate change 2014: summary for policymakers.* Geneva, Switzerland: Intergovernmental Panel on Climate Change. Retrieved from http://www.ipcc.ch/report/ar5/syr/

IRENA. (2018). *Renewable power generation costs in 2017.* Abu Dhabi, UAE: International Renewable Energy Agency. Retrieved from https://cms.irena.org/-/media/Files/IRENA/Agency/Publication/2018/Jan/IRENA_2017_Power_Costs_2018.ashx

Jaccard, M., & Dennis, M. (2006). Estimating home energy decision parameters for a hybrid energy-economy policy model. *Environmental Modeling and Assessment, 11*, 91-100.

Jacobsen, G., & Kotchen, M. (2013). Are building codes effective at saving energy? evidence from residential billing data in florida. *Review of Economics and Statistics, 95*(1), 34-49.

Jacobson, M. Z., Delucchi, M. A., Baxouin, G., Bauer, Z. A., Heavey, C. C., Fisher, E., . . . Yeskoo, T. W. (2015). 100% clean and renewable wind, water, and sunlight (wws) all-sector energy roadmaps for the 50 unites states. *Energy & Environment Science*. Retrieved from http://web.stanford.edu/group/efmh/jacobson/Articles/I/USStatesWWS.pdf

Jaffe, A., & Stavins, R. (1994). The energy efficiency gap: what does it mean? *Energy Policy, 22*(10), 804-810.

Juhász, L. (2011). Net present value versus internal rate of return. *Economics & Sociology, 4*(1), 46-53.

Karl, T., Melillo, M., & Peterson, T. (2009). *Global climate impacts in the united states.* New York: Cambridge University Press. Retrieved from www.globalchange.gov/usimpacts

Kelechava, B. (2017, August 7). ANSI/ASHRAE 103-2017: method for testing for annual fuel utilization efficiency of residential central furnaces and boilers. *American National Standards Institute*. Retrieved from https://blog.ansi.org/2017/08/ansiashrae-103-2017-furnaces-boilers-afue/#gref

Kelly, J., Fu, M., & Clinch, J. (2016). Residential home heating: the potential for air source heat pump technologies as an alternative to solid and liquid fuels. *Energy Policy, 98*, 431-442.

Koswo, H. &. (2008). *Methods of future and scenario analysis overview, assessment, and selection criteria.* Bonn, Germany: German Development Institute. Retrieved from https://www.die-gdi.de/uploads/media/Studies_39.2008.pdf

Kuchta, D. (2000). Fuzzy capital budgeting. *Fuzzy Sets and Systems, 111*(3), 367-385. Retrieved from https://www.sciencedirect.com/science/article/pii/S0165011498000888?via%3Dihub

Kuramochi, T. e. (2017). Ten key shot-term sectoral benchmarks to limit warming to 1.5°C. *Climate Policy*, 1-19. Retrieved from http://www.tandfonline.com/doi/full/10.1080/14693062.2017.1397495

Lapsa, M., Khowailed, G., Sikes, K., & Baxter, V. (2017). *Heat pumps in north america -- 2017 regional report.* Oak Ridge: 12th IEA Heat Pump Conference 2017. Retrieved from http://hpc2017.org/wp-content/uploads/2017/05/P.2.1.3-Heat-Pumps-in-North-America-%E2%80%93-2017-Regional-Report.pdf

Lazar, J., & Colburn, K. (2013). *Recognizing the full value of energy efficiency.* RAP Energy Solutions. Retrieved from https://www.raponline.org/wp-content/uploads/2016/05/rap-lazarcolburn-layercakepaper-2013-sept-09.pdf

Letendre, S., Bentley, B., & Dunn, D. (2014). Back to the future: assessing the fuel displacment potential using electricity in vermont for residential space and water heating. *The Electricity Journal, 27*(4), 95-101. Retrieved from https://www.sciencedirect.com/science/article/pii/S1040619014000797

Lin, W., Hirst, E., & Cohn, S. (1976). *Fuel choices in the household sector.* Oak Ridge National Laboratory.

MacGillivray, A., Jeffrey, H., & Wallace, R. (2015). The importance of iteration and deployment in technology development: a study of the impact on wave and tidal stream energy reserach, development and innovation. *Energy Policy, 87*, 542-552.

Mahone, A., Hart, E., Williams, J., Borgeson, S., Ryan, N., & Price, S. (2015). *California pathways: ghg scenario results.* Energy+Environmental Economics. Retrieved from https://energy.stanford.edu/sites/default/files/e3_pathways_ghg_scenarios_ucdavis_ccpm_final.pdf

Manomet Center for Conservation Sciences. (2010). *Biomass sustainability and carbon policy study.* Manomet, Massachusettes: Manomet Center for Conservation Sciences. Retrieved from https://www.manomet.org/sites/default/files/publications_and_tools/Manomet_Biomass_Report_Full_June2010.pdf

Matley, R. (2013). *Heat pumps: an alternative to oil heat for the northeast-input for planners and policy-makers.* Snomass, CO: Rocky Mountain Institute.

Michelsen, C. C., & Madlener, R. (2015). Switching from fossil fuel to renewables in residential heating systems: an empricial study of homeowners' decisions in germany. *Energy Policy, 89*, 95-105.

NASA. (2018). *Scientific consensus: earth's climate is warming*. Retrieved from Global Climate Change: https://climate.nasa.gov/scientific-consensus/

NEB. (2016). *Provincial and territorial energy profiles - nova scotia*. Retrieved from http://www.neb-one.gc.ca/nrg/ntgrtd/mrkt/nrgsstmprfls/ns-eng.html#s3

NEB. (2018, February 21). Market snapshot: steady growth for heat pump technology. *National Energy Board Canada*. Retrieved from https://www.neb-one.gc.ca/nrg/ntgrtd/mrkt/snpsht/2018/02-03htpmps-eng.html?=undefined&wbdisable=true

NEEP. (2014). *Northeast/mid-atlantic air-source heat pump market strategies report.* Northeast Energy Efficiency Partnerships. Retrieved from https://neep.org/sites/default/files/resources/NortheastMid-Atlantic%20Air-Source%20Heat%20Pump%20Market%20Strategies%20Report_0.pdf

NEEP. (2017a). *Northeast/mid-atlantic air-source heat pump market strategies report 2016 update.* Northeast Energy Efficiency Partnerships. Retrieved from https://neep.org/sites/default/files/NEEP_ASHP_2016MTStrategy_Report_FINAL.pdf

NEEP. (2017b). *Cold climate air source heat pump.* Northeast Energy Efficiency Partnerships. Retrieved from http://www.neep.org/initiatives/high-efficiency-products/emerging-technologies/ashp/cold-climate-air-source-heat-pump

Newell, R., & Siikamaki, J. (2015). *Individual time preferences and energy efficiency.* Cambridge, MA: National Bureau of Economic Research.

NRCan. (2004). *Heating and cooling with a heat pump.* Natural Resources Canada. Retrieved from http://www.nrcan.gc.ca/sites/oee.nrcan.gc.ca/files/pdf/publications/infosource/pub/home/heating-heat-pump/booklet.pdf

NRCan. (2012). *Heating with oil.* Natural Resources Canada. Retrieved from http://www.housing.yk.ca/pdf/heating_with_oil_nrcan.pdf

NRCan. (2015a). *Comprehensive energy use database - residential sector - canada [Summary Tables]*. Natural Resources Canada. Retrieved from http://oee.nrcan.gc.ca/corporate/statistics/neud/dpa/menus/trends/comprehensive/trends_res_ca.cfm

NRCan. (2015b). *Comprehensive energy use database - residential sector - canada [Table 27: heating system stock by building type and heating system type]*. Natural Resources Canada. Retrieved from http://oee.nrcan.gc.ca/corporate/statistics/neud/dpa/showTable.cfm?type=CP&sector=res&juris=ca&rn=27&page=0

NRCan. (2015c). *Comprehensive energy use database - residential sector - nova scotia [Summary Tables]*. Natural Resources Canada. Retrieved from http://oee.nrcan.gc.ca/corporate/statistics/neud/dpa/menus/trends/comprehensive/trends_res_ns.cfm

NRCan. (2015d). *Comprehensive energy use database - residential sector - nova scotia [Table 2: secondary energy use and ghg emissions by end-use]*. Natural Resources Canada. Retrieved from http://oee.nrcan.gc.ca/corporate/statistics/neud/dpa/showTable.cfm?type=CP&sector=res&juris=ns&rn=2&page=0

NRCan. (2015e). *Comprehensive energy use database - residential sector - nova scotia [Table 27 heating system stock by building type and heating system type]*. Natural Resources Canada. Retrieved from http://oee.nrcan.gc.ca/corporate/statistics/neud/dpa/showTable.cfm?type=CP&sector=res&juris=ns&rn=21&page=0

NRCan. (2015f). *Energy markets factbook 2014-2015*. Natural Resources Canada. Retrieved from http://www.nrcan.gc.ca/sites/www.nrcan.gc.ca/files/energy/files/pdf/2014/14-0173EnergyMarketFacts_e.pdf

NRCan. (2017a). *Air-source heat pumps*. Retrieved from http://www.nrcan.gc.ca/energy/publications/efficiency/heating-heat-pump/6831

NRCan. (2017b). *Fuel consumption taxes in canada*. Retrieved from http://www.nrcan.gc.ca/energy/fuel-prices/18885

NRCan. (2017c). *Glossary*. Retrieved from http://climate.weather.gc.ca/glossary_e.html#hdd

NRCan. (2017d). *Heat pump re-screening tool*. Retrieved from https://www.nrcan.gc.ca/energy/software-tools/17889

NRCan. (2017e). *Heating energy cost comparison: heat pump and electric heating systems*. Retrieved from http://www.nrcan.gc.ca/energy/publications/efficiency/heating-heat-pump/6835#table2

NRCan. (2017f). *Solar Thermal*. Retrieved from http://www.nrcan.gc.ca/energy/renewable-electricity/solar-thermal/7301

NRCan. (2017g). *Tidal energy project in the bay of fundy*. Retrieved from http://www.nrcan.gc.ca/energy/funding/current-funding-programs/cef/4955

NRCan. (2017h). *What is a heat pump and how does it work*. Retrieved from http://www.nrcan.gc.ca/energy/publications/efficiency/heating-heat-pump/6827

NRCan. (2018). *Energuide in canada*. Retrieved from http://www.nrcan.gc.ca/energy/products/energuide/12523

NRCan. (2019) *RETScreen.* Retrieved from https://www.nrcan.gc.ca/energy/software-tools/7465

NRDC. (2017). *The road from paris: canada's progress toward its climate pledge.* Pembina Institute. Retrieved from https://www.nrdc.org/sites/default/files/paris-climate-agreement-progress-2017-canada-ib.pdf

NRTEE. (2009). *Achieving 2050: a acarbon pricing policy for canada.* Ottawa: National Round Table on the Environment and the Economy. Retrieved from http://neia.org/wp-content/uploads/2013/04/carbon-pricing-advisory-note-eng.pdf

NRTEE. (2011). *Paying the price: the economic impacts of climate change in canada.* Ottawa: National Round Table on Environment and the Economy. Retrieved from http://tcan.ca/sites/default/files/files/NRTEE%20reports/NRTEE-Paying-the-Price_The%20Economic-Impacts-of-Climate-Change-for-Canada.pdf

NS DOE. (2010). *Renewable electricity plan.* Halifax, NS: Nova Scotia Department of Energy. Retrieved from https://energy.novascotia.ca/sites/default/files/renewable-electricity-plan.pdf

NS DOE. (2013). *Choose how you move: sustainable transportation strategy.* Halifax, NS: Nova Scotia Department of Energy. Retrieved from https://novascotia.ca/sustainabletransportation/docs/sustainable-transportation-strategy.pdf

NS DOE. (2015a). *Comfit review.* Halifax, NS: Nova Scotia Department of Energy. Retrieved from https://energy.novascotia.ca/sites/default/files/COMFIT%20Review.pdf

NS DOE. (2015b). *Electricity review report.* Halifax, NS: Nova Scotia Department of Energy. Retrieved from https://energy.novascotia.ca/sites/default/files/files/Final%20Review%20Report.pdf

NS DOE. (2015c). *Our electricity future nova scotia's electricity plan 2015-2040.* Halifax, NS: Nova Scotia Department of Energy. Retrieved from https://energy.novascotia.ca/sites/default/files/Our-Electricity-Future.pdf

NS DOE. (2017). *Sustainable transportation strategy*. Retrieved from https://novascotia.ca/sustainabletransportation/sustainable-transportation-strategy.asp

NSP. (2015, September). *2015 NSP Customer Survey - 2016 Load Forecast Report [Figure 9]*. Halifax, NS: Nova Scotia Power. Retrieved from https://www.nspower.ca/site/media/Parent/20170105%20NSPI%20to%20CA%20IR%20Responses%201-38%20REDACTED.pdf

NSP. (2016a). *Definitions*. Retrieved from https://www.nspower.ca/en/home/about-us/environmental-commitment/air-emissions-reporting/definitions.aspx

NSP. (2016b). *Air Emissions Reporting*. Retrieved January 26, 2016, from http://www.nspower.ca/en/home/about-us/environmental-commitment/air-emissions-reporting/

NSP. (2016c, January 26). Nova scotia power sets renewable energy record. *Nova Scotia Power*. Retrieved from https://www.nspower.ca/en/home/newsroom/news-releases/nova-scotia-power-sets-renewable-energy-record.aspx

NSP. (2017a). *2020 forecast*. Retrieved from https://www.nspower.ca/en/home/about-us/todayspower.aspx#forecast

NSP. (2017b). *Domestic service tariff*. Retrieved from https://www.nspower.ca/en/home/about-us/electricity-rates-and-regulations/rates/domestic-service-tariff.aspx

NSP. (2017c). *Heat pump financing*. Retrieved from https://www.nspower.ca/en/home/for-my-home/heating-solutions/heat-pumps/heat-pump-financing.aspx

NSP. (2017d). *Imported electricity*. Retrieved from https://www.nspower.ca/en/home/about-us/how-we-make-electricity/imported-electricity.aspx

NSP. (2017e). *Monopoloy status*. Retrieved from https://www.nspower.ca/en/home/about-us/how-we-operate/monopoly-status.aspx

NSP. (2017f). *What is a heat pump?* Retrieved December 10, 2017, from http://heatpumpssetyoufree.ca/about-heat-pumps/whats-a-heat-pump/

NSP. (2018). *Time-of-day rates*. Retrieved from https://www.nspower.ca/en/home/for-my-home/heating-solutions/electric-thermal-storage/tod-rates/default.aspx

NSUARB. (2017a). *Mandates electricity*. Retrieved from https://nsuarb.novascotia.ca/mandates/electricity/

NSUARB. (2017b). *Nova scotia power 10 year system outlook.* Nova Scotia Utility and Review Board.

NYSERDA. (2015). *Residential statewide baseline study [Volume 3: hvac market assessment]*. Albany, NY: New York State Energy Research and Development Authority. Retrieved from https://www.nyserda.ny.gov/-/media/Files/Publications/building-stock-potential-studies/residential-baseline-study/Summary-RES-Baseline.pdf

Ontario Energy Board. (2018). *Historical natural gas rates*. Retrieved from https://www.oeb.ca/rates-and-your-bill/natural-gas-rates/historical-natural-gas-rates

Palisade. (2019). *@risk decision tools suite.* Retreived from https://www.palisade.com/

Palmer, K., & Walls, M. (2017). Using informaiton to close the energy efficiency gap: a review of benchmarking and disclosure ordinances. *Energy Efficiency, 10*(3), 673-691.

PBO. (2016). *Canada's greenhouse gas emissions: developments, prospects and reductions.* Ottawa, ON: Office of the Parliamentary Budget Officer. Retrieved from http://www.pbo-dpb.gc.ca/web/default/files/Documents/Reports/2016/ClimateChange/PBO_Climate_Change_EN.pdf

PCF. (2016). *Canada's plan to address climate change and grow the economy.* Pan-Canadian Framework on Clean Growth and Climate Change -. Retrieved from http://publications.gc.ca/collections/collection_2017/eccc/En4-294-2016-eng.pdf

PCF. (2017). *First annual systhesis report on the status of implementation.* Pan-Canadian Framework on Clean Growth and Climate Change. Retrieved from https://www.canada.ca/content/dam/themes/environment/weather/climatechange/PCF-FirstSynthesis_ENG.pdf

PPUC. (2015). *2015 technical references manual.* Harrisburg, PA: Pennsylvania Public Utility Commission. Retrieved from http://www.google.ca/url?sa=t&rct=j&q=&esrc=s&source=web&cd=1&ved=0ahUKEwi-steyjMjVAhVF7oMKHaLhAnYQFggoMAA&url=http%3A%2F%2Fwww.puc.pa.gov%2Fpcdocs%2F1354209.docx&usg=AFQjCNEDLjNtQvdNUIviXQCxzq0QF1BnZw

RateSupermarket.ca. (2017, November 15). *Best Mortgage Rates*. Retrieved from https://www.ratesupermarket.ca/mortgages

Raymer, A. (2006). A comparison of avoided ghg emissions when using different kinds of wood energy. *Biomass and Bioenergy*, 605-617. Retrieved from https://www.sciencedirect.com/science/article/pii/S0961953406000389?via%3Dihub

Raynaud, M., Osso, D., Bourges, B., Duplessis, B., & Adnot, J. (2015). Evidence of an indirect rebound effect with reversible heat pumps: having air conditioning but not using it? *Energy Efficiency*, 847-860.

Renewable Electricity Regulations. (2010). c.[25], s.[5] (2004). Retrieved from https://novascotia.ca/just/regulations/regs/elecrenew.htm

Robins, A. (2017, August 25). Doing more with less: energy efficiency potential in canada. *Conference Board of Canada*. Retrieved from http://www.conferenceboard.ca/e-library/abstract.aspx?did=9069

Safa., A. F. (2015). Comparative thermal performance of a ground source heat pump and a variable capacity air source heat pump systems for sustainable houses. *Applied Thermal Engineering*, 279-287.

Schleich, J., Gassmann, X., Faure, C., & Meissner, T. (2016). Making the implicit explicit: a look inside the implicit discount rate. *Energy Policy, 97*, 321-331.

SEAI. (2012). *Dwelling energy assessment procedure.* Dublin, Ireland: Sustainable Energy Authority of Ireland. Retrieved from http://www.seai.ie/resources/publications/DEAP_Manual.pdf

Smith, V., & Moore, E. (2010). Behavioral economics and benefit cost analysis. *Environmental and Resource Economics, 46*(2), 217-234.

Standards Council of Canada. (2009). *Determining the required capacity of residential space heating and cooling appliances*. Retrieved from https://www.scc.ca/en/standardsdb/standards/4511

Stanley, S., Lyons, R., & Lyons, S. (2015). The price effect of building energy ratings in the dublin residential market. *Energy Efficiency, 9*, 875-885.

StatsCan. (2016). *Census Profile 2016.* Statistics Canada. Retrieved from http://www12.statcan.gc.ca/census-recensement/2016/dp-pd/prof/index.cfm?Lang=E

StatsCan. (2017). *Table 18-10-0001-01 monthly average retail prices for gasoline and fuel oil, buy geography.* Statistics Canada. Retrieved from http://www5.statcan.gc.ca/cansim/a26?lang=eng&retrLang=eng&id=3260009&&pattern=&stByVal=1&p1=1&p2=37&tabMode=dataTable&csid=

StatsCan. (2018). *Table 326-009 average retail prices for gasoline and fuel oil, by urban centre, monthly (cents per litre), CANISM (database).* Statistics Canada. Retrieved from http://www5.statcan.gc.ca/cansim/a47

Syed, A. (2011). Electric thermal storage option for nova scotia power customers: a case study of a typical electrically heated nova scotia house. *Energy Engineering, 108*(6), 69-79. Retrieved from https://www.tandfonline.com/action/showCitFormats?doi=10.1080%2F01998595.2011.10412169

Taylor, R. (2014, November 18). Imports keep n.s. fuel prices pumped. *Chronicle Herald*. Retrieved from http://thechronicleherald.ca/business/1251891-taylor-imports-keep-n.s.-fuel-prices-pumped

Tietenberg, T. (2009). Reflections: energy efficiency policy: a pipe dream or a pipeline to the future? *Review of Environmental Economics and Policy, 3*(2), 304-320.

UNFCCC. (2000). *Review of the implementation of commitments and of other provisions of the convention. unfccc guidelines on reporting and review.* Bonn, Germany: United Nations Office. Retrieved from https://unfccc.int/resource/docs/cop5/07.pdf

UNFCCC. (2015). *Canada's indc submission to the unfccc.* Retrieved from http://www4.unfccc.int/submissions/INDC/Published%20Documents/Canada/1/INDC%20-%20Canada%20-%20English.pdf

UNFCCC. (2016a). *Kyoto protocol to the united nations framework convention on climate change.* United Nations Framework Convention on Climate Change. Retrieved 2016, from https://unfccc.int/resource/docs/convkp/kpeng.html

UNFCCC. (2016b). *Synthesis report on the aggregate effect of intended nationally determined contributions.* United Nations Framework Convention on Climate Change. Retrieved from http://unfccc.int/focus/indc_portal/items/9240.php

UNFCCC. (2016c). *The Paris Agreement*. Retrieved from https://unfccc.int/process-and-meetings/the-paris-agreement/the-paris-agreement

UNFCCC. (2017). *Canada's 2017 nationally determined contribution submission to the united nations framework convention on climate change.* United Nations Framework Convention on Climate Change. Retrieved from http://www4.unfccc.int/ndcregistry/PublishedDocuments/Canada%20First/Canada%20First%20NDC-Revised%20submission%202017-05-11.pdf

USDOE. (2017a). *Furnaces and boilers*. Retrieved from https://energy.gov/energysaver/furnaces-and-boilers

USDOE. (2017b). *Heat pump systems*. Retrieved from https://www.energy.gov/energysaver/heat-and-cool/heat-pump-systems

USDOE. (2018a). *Electric resistance heating*. Retrieved from https://energy.gov/energysaver/home-heating-systems/electric-resistance-heating

USDOE. (2018b). *Radiant heating*. Retrieved from https://energy.gov/energysaver/radiant-heating

Wang, R., & Ge, T. (2016). *Advances in solar heating and cooling.* Duxford, UK: Woodhead Publishing.

Weis, T. P. (2012). *The high costs of cheap power.* Dayton Valley, AB: Pembia Institute. Retrieved from http://www.pembina.org/pub/high-costs-of-cheap-power

World Resources Institute. (2017). *CAIT climate data explorer*. Retrieved from http://cait.wri.org/historical/Country%20GHG%20Emissions?indicator%5b%5d=Total%20GHG%20Emissions%20Excluding%20Land-Use%20Change%20and%20Forestry&indicator%5b%5d=Total%20GHG%20Emissions%20Including%20Land-Use%20Change%20and%20Forestry&year%5b%5d=2014&sort

Zhao, H., Gao, Y., & Song, Z. (2017). *Strategic outlook of heat pump developments in china.* Beijing, China: 12th IEA Heat Pump Conference 2017. Retrieved from http://hpc2017.org/wp-content/uploads/2017/05/O.2.1.1-Strategic-outlook-of-Heat-pump-development-in-China.pdf