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Efficiency Evaluation of Hypothetical Whole Home Energy Efficiency Programs

in British Columbia, Canada

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Abstract

The purpose of this thesis is to determine if a hypothetical province wide, whole home, innovative energy efficiency financing program, could deliver more cost-effective energy savings and greenhouse gas emission reductions, than a comparable energy efficiency subsidy program in British Columbia, Canada. Based on data from the 2011/12 LiveSmart BC 3.0 and ecoENERGY subsidy programs, I construct three hypothetical energy efficiency program scenarios referred to as the: Subsidy Scenario, Finance Scenario, and Finance + Subsidy Scenario. The two finance based scenarios are designed to approximate the energy efficiency measure uptake, and operating cost, of innovative financing programs such as on-property tax bill financing, and on-utility bill financing.

The paper contributes to existing literature on energy efficiency programs in British Columbia by modeling the effects that different types of energy efficiency programs have on the net present values of residential energy efficiency measures, and by estimating the possible cost-effectiveness of energy efficiency financing programs in the province. With minor differences between each of the hypothetical energy efficiency program scenarios, the installation of almost 40,000 energy efficiency measures in 2011 is estimated to produce 14 petajoules of energy savings, and a reduction of 650,000 carbon dioxide equivalent tonnes of greenhouse gas, over the combined operating lifetimes of the measures. I estimate that each hypothetical energy efficiency program scenario would achieve an energy savings cost-effectiveness of $3 per gigajoule saved, and deliver greenhouse gas emissions reductions at a cost-effectiveness of $60 to $66 per carbon dioxide equivalent tonne.

Though the cost-effectiveness of all three hypothetical energy efficiency program scenarios are found to be similar, my findings show that under the Finance Scenario, funding for annual program operating costs may be sourced from the interest payments made by borrowers. In contrast, the Subsidy Scenario’s operating costs must be covered entirely by the administering organization.

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Abbreviations

ASHP – Air Source Heat Pump

BC – British Columbia

CMHC – Canada Mortgage and Housing Corporation

CO2e – Carbon Dioxide Equivalent

DSM – Demand Side Management

EE – Energy Efficiency

EI – Economic Instruments

F2024 – Fiscal Year 2024

GHG – Greenhouse Gas

GJ – Gigajoule

GLJPC – GLJ Petroleum Consultants

GSHP – Ground Source Heat Pump

GWh – Gigawatt hour

HELP – Home Energy Loan Program

HERO – Home Energy Renovation Opportunity

IRR – Internal Rate of Return

kWh – kilowatt hour

LIC – Local Improvement Charge

LIM – Low Income Measure

MEM – Ministry of Energy and Mines

Mt CO2e – Million Carbon Dioxide Equivalent Tonnes

NG to Elec – natural gas furnace to electric heater conversion

NRCan – Natural Resources Canada

NPV – Net Present Value

OPTBF – On-Property Tax Bill Financing

OUBF – On-Utility Bill Financing

PACE – Property-Assessed Clean Energy

PAPER – Property Assessed Payments for Energy Retrofits

PAYS – Pay As You Save

PJ – Petajoule

PSRL – Power Smart Residential Loan

PV – Present Value

ROE – Return On Equity

ROE – Return On Investment

2. Introduction

As 147 countries have now ratified the Paris Agreement, the reduction of greenhouse gas (GHG) emissions is at the forefront of policy makers' minds. At the federal level, Canada aims to lower GHG emissions to 30% below 2005 levels by 2030. Prior to this agreement, the provincial government of British Columbia (BC) had already set a provincial GHG emissions target of 80% below 2007 levels to be reached by 2050.

In BC, 6.5% of the provinces' GHG emissions were attributed to the residential sector in 2014 (BC Ministry of Environment, 2016b). The residential sector was also the 3rd largest consumer of energy at 17% (149.17 Petajoules (PJ)) of total annual provincial energy consumption (BC Ministry of Environment, 2016b; Statistics Canada, 2016c). Reducing residential GHG emissions would be an important step in helping Canada and the province of BC meet their ambitious GHG reduction targets.

The reduction of household energy use would go a long way to reducing GHG emissions, and in doing so increase energy security and accessibility by reducing energy demand and prices, and the need for the construction of additional costly power plants. An effective way of reducing household energy consumption is to increase the energy efficiency (EE) of the province's housing stock. This can be done by retrofitting homes with EE measures. An EE measure in the context of this paper is any energy efficient product that can be permanently installed into a home. Some examples are energy efficient insulation, fuel efficient furnaces and water heaters, and energy star rated windows and doors. Work done by the Pembina Institute estimates that for BC to reach an 80-100% reduction in GHG emissions from the building sector by 2050, 2500 or more households must perform EE retrofits each month with an average energy reduction of 25% (Frappé-Sénéclauze & Heerema, 2016). Two thirds of these households must also convert from non-electric heating fuel to electric heat.

Though increased residential EE may be in the best interest of individual households and the general population, it may still be necessary to implement programs which facilitate the uptake of EE measures. These residential EE programs have traditionally been taken on by the public sector, with the use of various EE measure subsidies in the form of capital cost rebates, buy back programs, and tax breaks to name a few. But EE subsidy programs face problems such as limited funding, program free riding, and EE uptake barriers such as the misaligned incentives of renters and owners as described by the principle agent problem.

In recent years, innovative forms of EE financing, such as on-property tax bill financing (OPTBF), and on-utility bill financing (OUBF) have been implemented in North America and Europe. Unlike traditional subsidy programs, innovative financing does not directly incentivise residential EE measure uptake, but instead reduces certain EE measure uptake barriers to a level where more households are able to engage in household EE upgrades. In addition, innovative EE financing programs may be more cost effective than subsidy based programs in terms of dollars spent per unit energy saved and GHG emission reduction.

In this paper, I seek to determine if a hypothetical province wide, whole home, innovative EE financing program could be operated more cost-effectively than a comparable EE subsidy program, in terms of dollars spent per unit energy saved, and GHG emissions reduction. Using data collected from the time of the province wide 2011 to 2012 LiveSmart BC 3.0 and ecoENERGY whole home EE retrofit subsidy programs, I will construct three hypothetical 2011/12 EE program scenarios referred to as the: Subsidy Scenario, Finance Scenario, and Finance + Subsidy Scenario. The Subsidy Scenario is modeled after the 2011/12 LiveSmart BC 3.0 and ecoENERGY subsidy programs and approximates the combined EE measure uptake and cost of these programs. The Finance and Finance + Subsidy Scenarios build off of the Subsidy Scenario, and are designed to approximate the EE measure uptake and cost of a long term, low interest loan programs similar to OPTBF or OUBF. I compare these three scenarios based on their estimated program participation, operating cost, and induced energy use and GHG emission reductions. The efficiencies of these three hypothetical EE scenarios, in terms of dollars spent per unit energy saved, and GHG emission reduction, are then compared.

3. British Columbia Context

Over the last ten years, three major whole home EE retrofit programs were offered in BC. These were the provincially operated LiveSmart BC program, and the federally operated ecoENERGY and Home Renovation Tax Credit programs. Subsidies and tax credits were provided by these programs for a wide range of home EE retrofit measures. As can be seen in Figure 1, these programs did not operate continuously. LiveSmart BC ran in four phases. One from 2008 to 2009, and the remaining three from 2010 to 2014. Similarly, ecoENERGY ran from 2007 to 2010, and again from 2011 to 2012. The Home Renovation Tax Credit was only available in 2009.

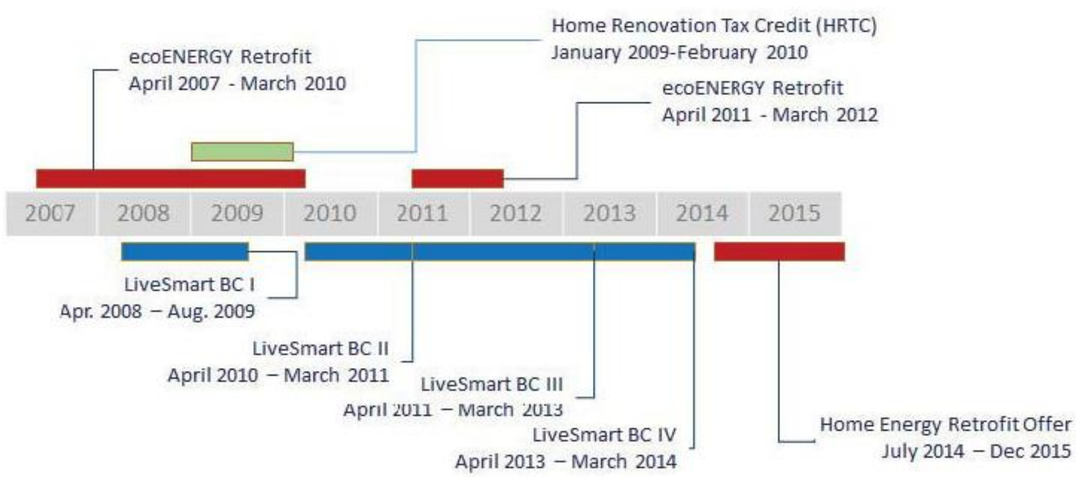

Figure 1: BC Home Energy Retrofit Programs. Adapted from "A Review of Whole Home Energy Retrofit Programs in British Columbia from 2007-2015," *by the BC Ministry of Energy and Mines, Energy Efficiency Branch, 2015, p. 5. Adapted with permission*

In this paper, I use data related to both the LiveSmart BC 3.0 and ecoENERGY programs, running from April 2011 to March 2012, to model the three hypothetical EE program scenarios noted in the introduction. Both historical programs offered subsidies on a range of EE measures directed at single detached homes. These measures included upgrades to a home's insulation, draftproofing, windows and doors, space heating, and hot water heating systems. During this time approximately 26,792 dwellings[1] were retrofitted with one or more EE measures (BC Ministry of Energy and Mines Energy Efficiency Branch, 2015). The programs were designed to compliment each other,

[1] A dwelling is defined by Statistics Canada as a set of living quarters with a private entrance (Statistics Canada, 2016a).

with each offering subsidies on similar EE measures. A household[2], which installed an eligible EE measure in their home, could receive a subsidy from each of the programs simultaneously. There were no other major EE programs operating in BC in 2011/12.

Today the bulk of residential EE programs in the province offer EE measure capital cost rebates to incentivise EE purchases. They are operated by the two major utilities in the province, BC Hydro and Fortis BC. These programs do not offer as comprehensive a selection of EE measures eligible for subsidisation as did the previous LiveSmart BC and ecoENERGY programs. There are also a few small finance and mortgage programs targeted at residential EE in BC. These are offered by Fortis BC, financial institutions such as Vancouver City Savings Credit Union and the Bank of Montreal, and the federal government through its crown corporation the Canada Mortgage and Housing Corporation (CMHC). From 2014 to 2015, 1,296 dwellings are reported as having undergone EE retrofits (BC Ministry of Energy and Mines Energy Efficiency Branch, 2015). This is significantly less than the number of dwellings retrofitted in 2011/12.

To better understand the residential sector effected by these EE programs, I will now review some of the most recent data (from 2010 to 2016) on BC's residential housing stock, energy consumption, and GHG emissions.

3.1 Housing Stock

The number of households in BC has steadily increased, from 1,804,530 in 2011, to 1,949,091 households in 2016. In 2011 an average BC household contained 2.5 individuals, with an average of approximately one household per dwelling (Statistics Canada, 2013).

Natural Resources Canada's (NRCan) Comprehensive Energy Use Database shows that BC currently has a total housing stock of 1,963,868 dwellings. Pre-1977 dwellings make up 27.6% of the housing stock in BC where as post-2000 dwellings make up 26.4%. Due to technology and legislative changes, dwellings constructed before 1977 would not have been built to the same efficiency standards as post-2000 homes, and may benefit the most from EE retrofits. Comparing

[2] A household is defined by Statistics Canada as "a person or group of persons who occupy the same dwelling and do not have a usual place of residence elsewhere in Canada or abroad." (Statistics Canada, 2016b, para. 1).

average dwelling space heating energy consumption in gigajoules (GJ), Table 1 shows that pre-1977 dwellings consume almost twice as much energy for space heating than do post-2000 dwellings.

Table 1: Private Dwellings by Period of Construction in BC, 2013

Period	Number of Dwellings	Share (%)	Average Dwelling Space Heating Energy Consumption (GJ)	Average Dwelling Space Heating Energy Consumption per unit area (GJ/m^2)
Before 1946	95,085	4.8	67.3	0.6
1946–1960	108,574	5.5	61.7	0.5
1961–1977	338,967	17.3	56.1	0.4
1978–1983	228,287	11.6	51.3	0.3
1984–1995	477,912	24.3	40.8	0.3
1996–2000	195,597	10.0	32.2	0.2
2001–2005	162,979	8.3	33.7	0.2
2006–2010	230,419	11.7	29.5	0.2
2011–2013	126,048	6.4	27.8	0.2
Total	1,963,868	100.0	43.5	0.3

Note: Adapted from Natural Resources Canada's Comprehensive Energy Use Database (2014).

In addition to their period of construction, household dwellings can be broken down into four main classifications: single-detached, single-attached, apartment, and other. In Table 2, these dwelling types are broken down by the number of households in each category.

Table 2: BC Households by Dwelling Type, 2014

Dwelling Type	Number of Households	% of Households
Single-detached dwelling	884000	47.9
Single-attached dwelling	262000	14.2
Apartment	650000	35.2
Other dwelling	48000	2.6
Total	1844000	99.9

Note: Adapted from Statistics Canada (2016).

In my analysis, I focus on the induced EE measure uptake by households living in single detached homes. This is because single detached homes make up the greatest portion of BC’s residential market, and because data is available from previous large scale EE programs directed towards single detached homes in the province. Like table 1, Table 3 breaks down the single detached housing stock by construction date and average energy consumption. Again it can be seen that pre-1977 homes use more energy for space heating than do post-2000 homes.

Table 3: Single Detached Homes by Period of Construction in BC, 2013

Period	Number of Single Detached Homes	Share (%)	Average Single Detached Home Space Heating Energy Consumption per household (GJ/household)	Average Single Detached Home Space Heating Energy Consumption per unit area (GJ/m2)
Before 1946	59,199	5.8	80.2	0.6
1946–1960	67,781	6.6	76.4	0.5
1961–1977	211,956	20.8	70.6	0.4
1978–1983	131,014	12.8	66.9	0.4
1984–1995	238,443	23.4	59.1	0.3
1996–2000	90,406	8.9	49.3	0.3
2001–2005	78,450	7.7	51.2	0.3
2006–2010	96,496	9.5	49.3	0.2
2011–2013	45,978	4.5	50.1	0.2
Total	1,019,723	100.0	62.1	0.3

Note: Adapted from Natural Resources Canada's Comprehensive Energy Use Database (2014).

3.2 Energy Consumption

In 2014, province wide residential energy use totaled 149 petajoules (PJ), making up 17% of BC's total energy consumption (Statistics Canada, 2016c). The bulk of energy used was in the form of electricity at 70.3 PJ, and natural gas at 77.7 PJ. This is in large part due to the fact that the majority of residential energy is consumed by electric and natural gas space heating and water heating technologies.

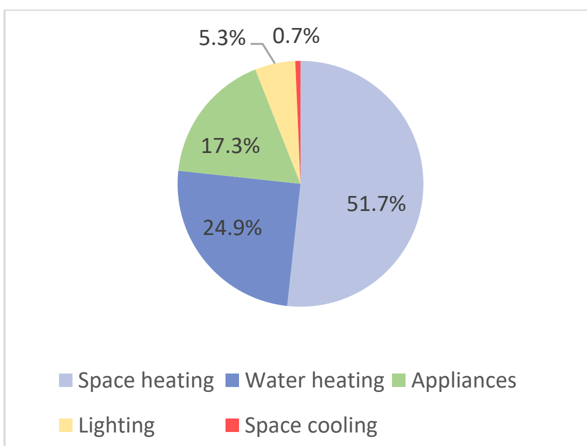

Figure 2: Residential Sector Energy End Use in BC, 2014. Adapted from Natural Resources Canada's Comprehensive Energy Use Database (2014)

Most, if not all, households in the province use electricity to some extent, with the average 2013 BC household using 36 Gigajoules (GJ) in a year (Statistics Canada, 2016d). The same cannot be said for natural gas, as about 69% of 2013 BC households used natural gas, with an average natural gas consuming household using 80GJ of natural gas in a year (Statistics Canada, 2016d). In 2013 there were approximately 1,015,400 natural gas heaters, and 606,100 electric heaters used by BC households (Natural Resources Canada, 2014). The greater number of natural gas heaters in use, combined with the relative low price of natural gas compared to electricity, may partially explain why natural gas made up a greater portion of total residential, and household energy use than electricity.

3.3 Greenhouse Gas Emissions

The most recent BC government data shows that the province's annual GHG emissions were about 64.5 million carbon dioxide equivalent tonnes (Mt CO2e) in 2014 (BC Ministry of Environment, 2016b). The bulk of these emissions (77.8%) were created through the consumption of energy. Residential sector emissions have remained at an average of 4.5 Mt CO2e since the year 2000, with slightly decreased levels from 2012 to 2014 (BC Ministry of Environment, 2016b).

Household GHG emissions can be estimated from the 2013 average household energy consumptions reported above by using conversion factors of 12 tonnes CO2e/GWh for electricity and 0.04987 tonne CO2e/GJ for natural gas (BC Hydro, 2016; BC Ministry of Environment, 2016a). This shows that an average natural gas and electricity consuming BC household emitted about 4.1 tonnes CO2e in 2013. Approximately 3% of these emissions came from electricity consumption and 97% came from natural gas consumption. Electricity consumption produced such a small proportion of a households GHG emissions because 92% of electricity produced by BC Hydro is hydroelectric (BC Hydro, 2017a).

4. The Need for Financial Instruments in the EE Market

Various studies from around the world have shown that there is an energy efficiency gap (IPCC, 2007; Letschert, Bojda, Ke, & McNeil, 2012; McNeil, Letschert, & de la Rue du Can, 2008) “between current energy use, on the one hand, and optimal energy use, on the other hand” (Jaffe, Newell, & Stavins, 2004, p. 82). In the following sections I address the different barriers to residential EE measure uptake which may in part be responsible for this energy efficiency gap, along with some of the possible financial instruments which can be used to address them.

4.1 Barriers to Energy Efficiency

Many different barriers and barrier categories have been proposed to explain this energy efficiency gap. Jaffe et al. (2004) and Gillingham, Newell, & Palmer, (2009) divide EE barriers into market and non-market failures. Where market failures result from “the failure of private markets to provide certain goods at all or at the most desirable level” (Jaffe et al., 2004, p. 79), while non-market failures are linked to consumer behavior which is “inconsistent with energy service cost-minimization” (Gillingham et al., 2009, p. 8). Jollands et al. (2010) take this a step further by creating a third barrier category, technological barriers, which represents the limited ability to update currently deployed energy infrastructure.

Some of the main barriers which lead to market and behavioral failures within EE investment, and which have been discussed throughout the literature (Jaffe et al., 2004; Jollands et al., 2010; Murphy & Meijer, 2011; Sathaye & Murtishaw, 2004), are:

- high initial capital cost
- limited financing
- long payback time
- the principle-agent problem
- incomplete information
- high transaction costs
- uncertainty of energy savings

4.1.1 Economic EE Barriers

It has been put forward by Golove & Eto (1996) that EE policy may be warranted when EE barriers result in market failures, high transaction costs, or the inability of individuals to help themselves. Many different economic instruments (EIs) have been designed and implemented around the world to address barriers to EE measure uptake. While there can be considerable overlap of economic instrument characteristics, they can be divided into two broad categories: subsidies, and financing. In this case subsidies refer to capital cost rebates, or other monetary incentives. Financing refers to the lending of money with the understanding that it will be repaid over time. The following are descriptions of four economic EE barriers that can be addressed with the use of EIs in the form of subsidies and financing. These EE barriers are: high initial capital cost, limited financing, long payback time, and the principle-agent problem.

High Initial Capital Costs

Possibly the greatest barrier to EE investment identified in the literature is the high initial capital cost of EE products and services, with residential EE measures typically ranging in price from $2,500 to $20,000 (Bierth, Peyman, & Svedova, 2010; de la Rue du Can, Leventis, Phadke, & Gopal, 2014). A 2013 survey undertaken by the Rexel Foundation and Opinion Way found that 63% of residents surveyed from across the USA, UK, France, and Germany reported that the high cost of EE measures, and other financial considerations, were the main reasons for not investing in EE measures (Allouhi et al., 2015). These upfront capital costs can be so high as to discourage households from investing in EE technology even if the purchase of these goods makes long term economic sense (de la Rue du Can et al., 2014).

This may be explained by findings from Hausman (1979), that show consumers place high discount rates, at an average of 29%, on energy consuming goods such as household appliances. A survey by Sanstad, Hanemann, & Auffhammer (2006) of regularly cited work on the topic of energy efficiency investment discount rates shows a range of average discount rates from 25-36% for relatively permanent residential EE measures such as space heating and thermal shell measures. These high consumer discount rates may lead consumers to discount future savings from EE technology more than is socially optimal, and lead to households underinvesting in EE technologies (Sutherland, 1991). Consumer discount rates may be inversely related to income as shown by Hausman (1979). This however runs contrary to findings from Houston (1983) that show an individual's income does not have a statistically significant effect on the discount rate they apply to energy saving goods. If consumer discount rates are inversely related to income, low income consumers with the highest discount rates may be more likely to invest in cheaper, less energy efficient appliances and retrofits than high income consumers, even though low income consumers could benefit the most from highly efficient measures in terms of reduced energy bills.

Using the after tax low income measure (LIM) for persons in BC in 2012, Statistics Canada reports that 11.3% of persons in economic families[3], and 27.4% of unattached individuals[4], were considered low income (Statistics Canada, 2012). This represents a significant portion of BC's population which may be less able to afford the high initial capital cost of residential EE measures.

Both subsidies and financing can be used to address the high initial capital cost of EE measures. Subsidies, such as tax breaks and rebates, are directed towards EE measures to directly or indirectly reduce the EE measure's initial capital cost relative to less efficient alternatives, and in turn increase EE measure uptake. Alternatively, financing can be used to reduce the immediate financial burden faced by households when purchasing EE measures by redistributing a measure's initial capital cost over the lifetime of the investment in the form of a low interest, long amortization period loan.

A major shortfall of subsidy programs is that people who would have purchased an EE measure even if a subsidy was not available, may still participate in, and benefit from, the program (Train, 1994). This is referred to as the free rider problem. The free rider problem can result in the inefficient allocation of government funds, with subsidies potentially going to higher income households that may have invested in EE measures even without the subsidy, while being ineffective at incentivising the uptake of EE measures by low income households. An evaluation done by BC Hydro of the 2008 to 2011 LiveSmart BC subsidy program found that free riders made up 44% of program participants (BC Hydro, 2013).

[3] An economic family as defined by Statistics Canada is "a group of two or more persons who live in the same dwelling and are related to each other by blood, marriage, common-law or adoption" (Statistics Canada, 2011a, para. 5).
[4] An unattached individual as defined by Statistics Canada is "a person living either alone or with others to whom he or she is unrelated, such as roommates or a lodger" (Statistics Canada, 2011a, para. 5)

Free riders may be deterred from participating in an EE financing program if they would be economically better off paying for their home's EE retrofit out of pocket rather than taking out a loan for money they already have. If free riders do participate in a financing scheme, their effect on program spending may be much less than if they participated in a subsidy program, as they will only be increasing the cost of administering the program, and not receive subsidies directly from the administering organization.

Limited Financing Options

As the price of EE measures can range from $2,500 to $20,000, even if a subsidy is available, many households may need to acquire financing to cover the upfront cost an EE measure (Bierth et al., 2010). These households may be faced with a limited range of financing products. Traditionally, independent small loans of around $10,000 are lent on an unsecured basis, and are amortized over a short period of time at a relatively high interest rate (Bierth et al., 2010). An unsecured loan such as this may carry a rate of interest so high as to make it financially unattractive for use in the purchase of an EE measure. In addition, eligibility for such a loan will likely depend on a prospective borrower's credit history, making it difficult for households with poor credit to access. On the other hand, secured loans such as mortgages, typically have longer amortization periods and may have affordable interest rates. However, secured loans may not generally be leant out in the relatively small amounts required for the investment in typical EE measures.

Subsidies may be able to indirectly address the barrier of limited financing. If a household is eligible to receive traditional unsecured financing, but chooses not to because the resulting monthly loan payments are too high, a large enough subsidy could reduce the capital cost of an EE measure to the point where traditional financing may become viable due to the resulting reduction in monthly loan payments. If on the other hand a household cannot access financing due to poor credit, an EE measure subsidy may have a limited effect on their decision/ability to purchase an EE measure.

Innovative forms of financing, such as OPTBF and OUBF, can be designed to address this barrier. Instead of depending on a borrower's credit history, financing schemes can be created that use a different measure of loan eligibility, such as a household's utility payment history**.** Innovative financing tailor made for EE measure financing may also be offered at lower interest rates and over longer amortization periods than traditional financing.

Long Payback Time and Non-Transferability

The return on an EE measure investment in the form of energy savings usually accrues over an extended period, and it can take up to 10 to 30 years before a household fully recoups their investment. If the household chooses to move before their EE investment has been fully recouped, they may not fully benefit from their initial investment unless the remainder of the EE measure's capital cost can be transferred to the new home owner. In BC the average time a household lives in their home (owned or rented) before moving is about 12.8 years (BC Hydro, 2015). Because of this, many BC households may be discouraged from making EE measure upgrades due to the long payback time EE barrier.

A subsidy cannot be used to transfer the remainder of the EE measure's capital cost to the new home owner, but by reducing the initial capital cost of an EE measure, a subsidy can effectively shorten the amount of time required by a household to recoup their initial EE investment. The amount by which a subsidy can shorten this recoupment period depends on the size of the subsidy, the initial capital cost of the EE measure, the savings generated by the measure, the lifetime of the measure, etc. If a subsidy is unable to shorten this period sufficiently, actual mechanisms for transferring the remaining unrecouped EE measure capital cost may be required to overcome this barrier.

One way of transferring an EE measure's remaining capital costs is through the price of the house itself. However, it may be difficult to perfectly reflect the increased quality of a home due to the installation of an EE measure with an increase in the price of the home. This could in large part be due to a buyer's lack of information related to the benefits of installed EE measures (Bardhan, Jaffee, Kroll, & Wallace, 2014). However, new research in the U.S. has shown that EE home labeling programs such as Energy Star can have a positive effect on the prices of EE homes (Walls, Gerarden, Palmer, & Bak, 2017). Labeling programs such as this could allow for the transfer of an EE measure's remaining capital costs through the increased price of the house itself.

In the absence of such programs, it may be in the household's interest to arrange for the direct transfer of the remaining EE measure debt to the new owner. Typical capital cost payment mechanisms do not allow for the smooth transfer of debt between the previous and new home owner. Innovative financing schemes can be designed in ways which allow for the transfer of ownership of the debt owed on an EE investment. This can allow for not only the distribution of initial capital cost over time, but the efficient allocation of debt amongst the various parties who benefit from the EE measure over time as well.

Principle-Agent Problem

The principle-agent, or split incentives, problem arises in the residential sector when a property owner/landlord is responsible for the purchasing of residential EE technology but the renter is responsible for paying the property's energy bill. This greatly reduces the landlord's incentive to pay for EE upgrades to the home as they will not be the ones who directly benefit from lower monthly energy costs (Jaffe et al., 2004). In 2011, about 30% of all BC households rented their dwelling (Statistics Canada, 2011b). The proportion of BC households renting single-detached homes in 2011 was lower at 10.5% (Statistics Canada, 2011b).

Simply receiving a subsidy may not be enough to encourage a landlord to invest in EE retrofits as they will still have to cover the remainder of the EE measure's capital cost. The likelihood of a landlord investing in an EE measure is reduced if they will not directly receive any benefit from the upgrade. Shifting the future monetary benefits of an EE measure from the renter to the landlord may increase a landlord's willingness to invest in the EE measure. One way of accomplishing this may be through negotiating an increase to a tenant's rent to reflect energy bill savings induced by the installation of the new EE measure. Alternatively, financing schemes can be created to address the principle-agent problem (Charlier, 2015). With the consent of the tenant, the landlord may finance an EE measure, and have the tenant, who benefits from lower energy bills, cover the monthly loan payments through an extra item on their energy bill. This is referred to as OUBF and is discussed in the follow section, along with other EE financing instruments.

4.2 Financing Instruments

I will now review the types of financing instruments that can be used to address these residential sector EE barriers, with a focus on innovative EE financing in the form of OPTBF and OUBF. Financing instruments in the context of this paper are loans which can be taken on by households from lenders such as financial institutions and governments. These loans can be repaid in a variety of different ways, some of which will be discussed below.

EE financing can be used to cover the initial capital costs involved in purchasing and installing EE products, and can even be paid off over time by the energy bill savings created by the installed EE measures. Financing programs can also be designed in such a way as to be self-sustaining. Payments made by households on their debt can be returned to a fund for the financing tool in question. This can reduce costs, increase stability, and allow for the long-term provision of such EE programs. Funding for financing programs can come from government, but may also be offered by the private sector if it can be shown that investment into residential EE is profitable.

In addition to overcoming the barriers described in the previous section, EE financing may be able to encourage deeper energy saving retrofits which might otherwise be initially far too expensive for consumers to pay for out of pocket (Persram, 2011). Also, depending on the financing agreement, it may be possible for a homeowner to use financing to pay for non-EE upgrades to their home in addition to EE measures, thus encouraging home owners to have EE work done on their home at the same time as basic renovations.

4.2.1 Traditional Unsecured and Secured Loans

The most basic means of financing an EE retrofit of a household's home is with the use of a traditional unsecured or secured loan, such as credit card debt, or a mortgage, respectively. Unsecured loans will generally be smaller, have higher interest rates, and have shorter amortization periods than secured loans (State and Local Energy Efficiency Action Network, 2014). To qualify for a secured loan a consumer must have some form of collateral that can be given to the lender in case the borrower defaults on their loan. Traditional financing can be used by eligible borrowers to address the EE barrier of an EE measure's high initial capital cost, but may be unable to address the EE barriers of limited finance, long payback period/non-transferability, and the principle-agent problem.

The accessibility of unsecured and secured loans generally depends on the borrower's credit rating, and those with poor credit may not be eligible for either form of traditional financing. Due to the high interest payments on unsecured loans and the secured loan's need for collateral, it may also not be possible for low income households to attain either form of financing.

Unsecured loans may have difficulty in addressing the EE barrier of long payback period/non-transferability as they may not be explicitly designed to be transferred between borrowers. It might be possible to address this barrier with a secured loan, such as a mortgage, that can be transferred to a new home owner with permission from the lender, but secured loans like this are typically much larger than the $2,500 to $20,000 cost of typical EE measures.

Traditional financing may be able to address the principle-agent problem if an agreement can be reached between the landlord, who would be borrowing the funds, and the tenant, who would be making payments on the debt. Such an agreement may not be reachable though if the generally high rate of interest on unsecured loans results in a tenant's new loan payments being greater than the energy bill savings they would receive from the installation of an EE measure in their rented dwelling. Again, secured financing may have a lower interest rate, but will generally not be leant out in the relatively small amounts needed to purchase typical EE measures.

For these reasons, traditional unsecured and secured loans may be able to address the EE barrier of high initial capital cost, but are generally unable to address the EE barriers of limited finance, long payback period/non-transferability, and the principle-agent problem.

4.2.2 On-Property Tax Bill Financing

On-property tax bill financing (OPTBF) uses low interest loans, which are attached to a retrofitted property, to cover the upfront capital costs of EE measures. The repayment of the loan is secured through a tax lien on the property, which reduces lending risk and allows for reduced interest rates and longer amortization periods (Supple & Nix, 2010). Loan repayment is then made monthly or annually through an additional item on the household's property tax bill.

This type of program may be able address many of the EE barriers that traditional financing cannot. It can increase access to EE finance as obtaining a loan may not depend on, or effect, a homeowner's credit history (HERO, 2016). When the property is sold the repayment obligation is transferred to the new homeowner due to the loan repayment being secured through a tax lien on the property itself, thus overcoming the long-payback time barrier (Supple & Nix, 2010). This transferability, coupled with a long repayment period, may make deep energy saving retrofits more cost effective than could be achieved with the use of a more traditional form of financing (Bierth et al., 2010). The OPTBF scheme may also be able to address the principle agent problem. As loan payments are made through a home's property tax bill, it may be possible to transfer these property tax bill increases to a renter, in the form of increased rent. The framework for this type of cost transfer exists in the USA where "property assessments normally qualify as eligible pass-through expenses" (Supple & Nix, 2010, p. 4). These pass-through expenses are additional variable expenses that are agreed to be paid by the tenant upon the signing of their rental agreement. It may be possible to implement a similar system in BC. However, under BC's current Residential Tenancy Act, a landlord may only increase their rental rate by more than the allowed annual rate increase if they first gain approval from their tenant, or receive permission from an arbitrator (Residential Tenancy Branch, 2017).

OPTBF is referred to as Property-Assessed Clean Energy (PACE) in the U.S., and Local Improvement Charge (LIC) or Property Assessed Payments for Energy Retrofits (PAPER) in Canada. According to PACENation there are currently 39 operating commercial and/or residential PACE programs across 19 states, with three more in development (PACENation, 2016). One working example of the PACE scheme is the Home Energy Renovation Opportunity (HERO) program.[5] The HERO program offers 5 to 25 year low interest loan terms, a verified retrofit contractors contact list, and project pricing reviews (HERO, 2016). Before funding is made available, the program requires that all building permits are in place and that all products to be installed meet current energy efficiency standards (HERO, 2016).

This type of financing is also gaining exposure in Canada. The Halifax Solar City LIC pilot program which began in 2012 lead to the installation of 388 solar hot water systems and has recently been approved to operate for another three years (Halifax Regional Council, 2015). In 2014 the city of Toronto launched the Home Energy Loan Program (HELP). Unlike the Solar City program which focuses on one specific EE measure, HELP offers financing on a range of residential EE measures, with an expected average loan size of $10,000 (Morgan, Lothian, & Thibault, 2015).

[5] Note that this is different from the Home Energy Rebate Offer (HERO) program that has operated in BC.

There has been some pushback against OPTBF schemes from American mortgage companies that have felt threatened by the prospect of an EE loan taking priority over a home's mortgage in the event of a default (Goodward, 2011). That being said, a 2013 study performed by the UNC Center for Community Capital found that mortgage default was 32% less likely for energy efficient homes (Kaza, Quercia, & Tian, 2014). This finding may help to mitigate a mortgage provider's concerns related to on-property tax financing. In addition, the U.S. Department of Energy recently recommended that PACE loans should remain with a property after foreclosure and be taken on by the next owner of the property (U.S. Department of Energy, 2016).

For the past three years the percentage of BC residential mortgages in arrears has been declining steadily. As of May 2016 it was at 0.26% (Canadian Bankers Association, 2016). This relatively low mortgage default rate in BC may help assuage fears mortgage firms may have about allowing OPTBF to occur in BC.

4.2.3 On-Utility Bill financing

The defining feature of on-utility bill financing (OUBF) is that loan repayments are made through an extra item on a household's utility bill. By linking to the utility's existing billing system, the lender's administrative costs can be reduced (Goodward, 2011). And as payments are secured through the utility bill, borrowers have an incentive to make payments on time as default may result in the disconnection of their utility (Bierth et al., 2010). These reduced administrative costs, and secured payments, may allow for lower interest rates, and longer amortization periods, that can make financing more accessible to low income households. This type of financing can also be accessible to households with low credit scores as eligibility can be based on a household's utility payment history and not credit history (Bierth et al., 2010).

If payments can be linked to the home's meter, then the user of the meter will be responsible for loan payments (de la Rue du Can, Shah, & Phadke, 2011). This can allow for the easy transfer of payments between occupants of the home and address the EE barrier of a long-payback time. In addition, because the loan repayment is included on the utility bill, payments can be easily taken on by tenants who pay for their own energy bills, thus addressing the principle-agent problem. To successfully address this barrier, the landlord and tenant would need to agree on what EE measures were to be installed, and made fully aware of how these changes would affect the tenant's utility bill.

Several OUBF programs have been implemented by Manitoba Hydro since 2001. As of 2013 over 17 percent of Manitoba homeowners had participated in these programs (Zimring et al., 2014). Two of these programs being the Power Smart Residential Loan (PSRL) which has run from 2001 to the present, and the Power Smart Pay As You Save (PAYS) Financing program which has run from 2012 to the present. From 2011 to 2013 the PSRL delivered 70,358 loans to households with a total value of $290 million, while from 2012 to 2013 PAYS had delivered 52 loans with a total value of $224,947 (Zimring et al., 2014). The PAYS program was offered to encourage the uptake of EE measures by low income and low credit households that may not have been able to participate in the utility's other financing programs (Zimring et al., 2014). To that end, unlike it's other financing programs, only EE measures that result in energy bill savings great enough to completely offset a measures loan payments are eligible for PAYS financing (Zimring et al., 2014).

There is currently one OUBF program being operated in BC. It is operated by the City of Nelson and is called the EcoSave on-utility bill financing program. Nelson is a small city in south-central BC with just over 10,000 residents. Loans for EE retrofits are offered to home owners in the City of Nelson, who are Nelson Hydro customers, and have a strong utility payment history. EcoSave loan eligibility does not depend on personal income, debt, or credit details, and can be approved for 5 to 10 year terms, at a 3.5% fixed interest rate, with a maximum size of $16,000. Although the loan is technically non transferable and must be paid in full at the time the home is sold (City of Nelson, 2016), the buyer may agree to pay off the remainder of the loan and arrange to take on a new loan with the city, under their name and for the previous amount owed. Though this work around exists, it has yet to be used by any EcoSave participants (C. Proctor, personal communication, November 29, 2016).

Provided the EcoSave loan applicant meets the above stated requirements, this loan is accessible to low income households with poor credit. As was noted above in the description of on-utility bill financing, the Eco Save program may also be able to address the principle agent problem because the loan repayments are attached to the household's utility bill. Unfortunately, this is a small program which only serves Nelson Hydro customers. The city of Nelson has been able to offer this program through its wholly owned and operated electrical utility, Nelson Hydro.

All four types of financing reviewed above are being used to finance EE measures in various places around the world. The use of innovative forms of financing, such as OPTBF and OUBF schemes, is increasing as can be seen from the spread of the PACE programs in the U.S. and LIC's in Halifax and Toronto. These innovative forms of EE measure financing may be better able to address the four economic EE barriers reviewed in the previous section than traditional unsecured and secured financing. For this reason, it may be worth considering the use of these innovative forms of financing in BC's residential EE market.

5. Previous Research in BC

My work builds off of research done by Poirier et al. in the 2012 report "An Analytical Foundation in Support of MEM's On-Bill Financing Program for British Columbia". This report, commissioned by the BC Ministry of Energy and Mines (MEM), provides an analytical framework for on-utility bill financing in the province.

The Poirier et al. (2012) report uses a borrower's estimated cash flow, resulting from the loan payments on an installed EE measure, and the EE measure induced energy bill savings, to provide cost benefit analysis on the financing of 732 combinations of EE measures and housing archetypes. The cash flow of an EE measure investment is reported in terms of induced monthly energy bill savings, minus monthly EE measure loan payments. An EE measure/archetype combination is said to be cash flow positive, and beneficial to the borrower, when monthly energy savings are greater than monthly loan payments.

The report and accompanying excel based analysis tool contain data on: BC housing archetypes, energy savings induced by 40 individual EE measures (calculated using HOT2000 energy modeling software), and EE measure capital costs. The EE measures examined in this report were all eligible for subsidisation under the 2011/12 LiveSmart BC 3.0 and ecoENERGY programs.

The Hot2000 EE measure energy savings modeling carried out by Poirier et al. (2012) uses 24 sub-archetypes meant to represent buildings in different locations across the province. Each sub-archetype is made up of one of six building archetypes, one of four climate zones, and one of two space heating energy sources. The EE measures are modeled as if they have been independently installed into each of the 24 sub-archetypes. The total capital cost of each EE measure has been collected by Poirier et al. (2012) from various provincial sources such as the BC utilities, costing reports, and equipment distributors.

Poirier et al. (2012) find that 35% of the EE measure/archetype combinations tested are cash flow positive when using an interest rate of 5% and an amortization period of ten years. They also find that 44% of the EE measure/archetype combinations for electrically heated homes are cash flow positive, whereas 27% of the EE measure/archetype combinations for natural gas heated homes are cash flow positive. They report that, of the EE measures tested, attic and wall insulation are most likely to be cash flow positive.

In this paper I build off of the work done by Poirier et al. (2012) to calculate the 2011/12 net present value (NPV) of a variety of permanent residential EE measures that were subsidised under the 2011/12 LiveSmart BC 3.0 and ecoENERGY programs. I then use these NPVs as a means of comparing and estimating EE measure uptake between three hypothetical EE program scenarios, with assumed start dates 2011. From this I estimate the program operating cost of each of these three hypothetical EE program scenarios, and their corresponding values of cost-effectiveness in terms of dollars spent per unit energy saved, and dollars spent per unit GHG reduced.

6. Methodology

6.1 Program evaluation

The methodological framework that I use in this research is that of program evaluation. Many definitions of program evaluation exist. It has been defined by Patton (2008) as the methodological gathering of data related to the operation and outcome of a program, for the purpose of making informed assessments of the program, its effectiveness, and future program design decisions. It has also been defined as a way to determine "how successful a policy has been, whether it met its objectives, how far it fell short, and what might be done to improve its impact" by Pal (2010), p. 305.

Pal divides the practice of program evaluation into three categories (Pal, 2009, p. 310):

1. Process Evaluation: The examination of a program's design, structure, and activities.
2. Impact Evaluation: Assessment of the effect a program has on its target issue.
3. Efficiency Evaluation: The use of cost-benefit and cost-effectiveness analysis to determine the economic value of a program.

In this paper, I use efficiency evaluation to compare the predicted outcomes of three hypothetical EE programs that are modeled on data from the 2011/12 LiveSmart BC 3.0, and ecoENERGY programs.

6.1.1 Efficiency Evaluation

Program efficiency evaluation is the examination of the costs associated with reaching a program's outcome. As noted by Pal (2010), cost-benefit analysis and/or cost-effectiveness analysis are commonly used in program efficiency evaluations.

Cost-Benefit Analysis

Cost-benefit analysis is the comparison of a program's monetary costs, with its monetary benefits. From this cost-benefit comparison, the economic value of an investment can be determined. The "investment" in this research, from the household's perspective, is the EE measure to be purchased and installed in their home.

Several different methods can be used to analyse the economic value of an investment, such as: net present value (NPV), return on investment (ROI), return on equity (ROE), and internal rate of return (IRR). In this paper I calculate the NPV of each EE measure[6], given the characteristics of the home it is installed in, and the program scenario it is offered through.

Net Present Value

NPV is the present value (PV) measure of an investment net of any costs. An investment's NPV is calculated by summing it and the series of its resulting future positive cash flows which have been discounted to their present-day value, and subtracting this from the sum of any negative cash flows related to the same investment which have also been discounted to their present-day value.

One of the difficulties with calculating the NPV of an investment can be in choosing the correct discount rate. The higher the discount rate the less value is placed on a future cash flow and vice versa. If all investors have the same time value of money, they may still have varying discount rates due to their willingness to take on risk. An investor who perceives an investment as being overly risky or difficult to undertake may assign a larger discount rate to that investment than another investor who sees it as being less risky or has the means which make the investment easier to undertake. For this reason, the discount rate can be difficult to estimate correctly while at the same time being an integral part of the NPV calculation. Previous research on the topic of residential energy efficiency investment discount rates for permanent EE measures, such as space heating systems and thermal shells, shows a range of discount rates of 25-36%. Taking this into account, I use a discount rate of 30% in my EE measure NPV calculations.

Cost-Effectiveness Analysis

Cost-effectiveness analysis compares the dollars spent by a program, with a non-monetary quantity that is representative of the programs outcome. The cost effectiveness of each of the EE program scenarios constructed in this paper, are reported in dollars per unit induced energy savings ($/GJ), and dollars per unit induced GHG emissions reductions ($/tonne CO_2e).

Many papers have been written on the cost effectiveness of EE programs. A great number of these are reviewed by Gillingham et al. (2006, 2009). These studies can be divided into ex ante

[6] The NPV is calculated with the assumption that the EE measures would have been installed in 2011, and therefore the results are in 2011 dollars.

engineering data analysis, and ex post econometric analysis (Gillingham et al., 2009). Typically, ex ante engineering data analysis will result in lower costs per unit of energy savings than ex post econometric analysis (Arimura, Li, Newell, & Palmer, 2012). As ex post data in the form of actual measurements of the energy savings resulting from the installation of an EE measure is not available, I use ex ante data in my analysis. This ex ante data being predicted EE measure induced energy savings. Because of this, my results may show lower costs per unit energy savings values than had ex post data been used. Previous research in the United States has generated a range of cost-effectiveness values. A review of electricity efficiency programs by Gillingham, Newell, & Palmer (2004) finds program cost-effectiveness values ranging from $0.008 to $0.229 per kilowatt hour (kWh) saved.[7] While Friedrich, Eldridge, York, Witte, & Kushler, (2009) found values ranging from $0.016 to $0.033 per kWh in there review of utility sector electricity efficiency programs, and $0.27 to $0.55 per therm for utility sector natural gas efficiency programs.[8] In terms of cost-effectives GHG reductions, in 2015 Fortis BC residential energy efficiency programs delivered GHG

A common problem faced by cost-effectiveness analysis is the difficulty of accounting for program free riders (Gillingham et al., 2009). As the free rider would have acted in the absence of an EE program, the additional costs imposed by the free rider on the EE program should be accounted for, but the benefits, such as reduced GHG emissions, due to free rider participation should not be included in the analysis (Gillingham et al., 2009). Because of this, if free riders are unaccounted for, their participation in an EE program may make the program seem more cost-effective than it really is.

[7] Reported in 2002 US Dollars, 1kWh = 0.0036GJ
[8] Reported in 2007 US Dollars, 10Therm = 1.0551GJ

7. Modeling Residential EE Programs

In the previous sections I have made a case for the use of innovative financing schemes in BC on the basis that they are better able to address certain economic EE barriers than traditional subsidy and finance based EE programs. I will now assess the economic merits of large scale innovative EE financing in BC at the program level. To do this I will model and compare three hypothetical EE program scenarios. These being the Subsidy Scenario, Finance Scenario, and Finance + Subsidy Scenario. As noted in the introduction, the Subsidy Scenario is modeled after the 2011/12 LiveSmart BC 3.0 and ecoENERGY subsidy programs and approximates the EE measure uptake and cost of these programs. The Finance and Finance + Subsidy Scenarios build off of the Subsidy Scenario, and are designed to approximate the EE measure uptake and cost of a long term, low interest loan program, such as an on-property tax or on-utility bill EE financing program. The Finance Scenario uses financing alone to induce EE measure uptake, whereas the Finance + Subsidy Scenario uses a combination of financing and minor subsidies.

In this section I will describe how data from these programs is used to model my three EE program scenarios, estimate their possible EE measure uptake, and in turn, their operating costs and efficiencies. The study progresses as follows:

1. **Housing Archetypes:** Construct 20 different housing archetype groups that are representative of homes that have undergone EE retrofits.
2. **Program Participation:** Determine the number of households assumed to have participated in the historical LiveSmart BC 3.0 and ecoENERGY programs. These participation rates are then applied to the Subsidy Scenario model.
3. **Energy Efficiency Measures:** A selection of the individual EE measures which had been incentivised and installed during the historical subsidies program are chosen for modeling in the hypothetical EE program scenarios. For ease of analysis these EE measures are combined into seven categories: Basement/floor insulation, Attic insulation, Walls insulation, Draftproofing, Space Heating (HVAC), Windows/Doors, and Domestic hot water heating.

4. **Net Present Value Calculations:** Three sets of NPVs are then calculated for these selected individual EE measures; one for each EE program scenario, given each scenario's specific economic characteristics such as the dollar amounts of subsidies and loans applied.
5. **Assessing EE measure uptake**: I have data on the number of homes that were retrofitted, but data on the number of individual EE measures which were installed due to the 2011/12 LiveSmart BC 3.0 and ecoENERGY EE programs is not available. I therefore estimate the number of individual EE retrofits performed in BC as a result of the historical 2011/12 programs, and apply this to my Subsidy Scenario. EE measure uptake induced by the hypothetical Subsidy Scenario is assumed to be the same as the estimated historical EE measure uptake. Using the EE measure NPVs as a point of comparison between the three EE program scenarios, I then estimate the EE measure uptake induced by two hypothetical finance based EE programs, and in turn estimate the total cost and efficiency of these scenarios.

7.1.1 Housing Archetypes

A housing archetype is a representative model of a set of homes which share similar characteristics. Using housing archetypes removes the need to conduct a separate analysis on each individual home in a dataset. Instead, the analysis conducted on an archetypal home can be related to the set of homes which it represents. Housing archetypes provide a fast and simple way of performing energy use evaluations on a large set of homes.

The archetypes I use in this study are based on housing archetypes that were constructed by Poirier et al. (2012). The archetypes created by Poirier et al. (2012) were based on data from the 2010 Residential Existing House Statistics report submitted to Terasen Gas by SAR engineering ltd, which in turn sourced it's data from home energy audits of ecoENERGY program participants. For each of these archetypes, Poirier et al. (2012) calculated the energy savings that would have been induced by the separate installation of certain individual EE measures. The 40 individual EE measures assessed by Poirier et al. (2012) were all subsidized under the LiveSmart BC 3.0 and ecoENERGY programs.

In order to use the individual EE measure energy savings values calculated by Poirier et al. (2012) in this paper, I had to first divide the 2011/12 homes in the EnerGuide Home Energy Audit database into archetype groups that were comparable to the housing archetypes constructed by Poirier et al. (2012). Due to data constraints, and for ease of use, I simplified the detailed Poirier et al. (2012) housing archetypes down to a home's construction date, number of storeys, HVAC system energy source, and climate zone. This produced 20 unique simplified housing archetypes. The homes recorded in the 2011/12 NRCan EnerGuide database were then broken down into their respective archetypes using these simplified archetype characteristics.[9]

The simplified archetype characteristics used to separate the homes in the NRCan EnerGuide database into 20 different archetype groups are listed in Table 4. There are 16 different housing archetypes involving homes located in the two Southern climate zones, and four different archetypes involving homes located in the two Northern climate zones. A home located in a Southern climate zone is characterised by it's construction date, number of storeys, and HVAC energy source. Because there are fewer single detached homes in Northern BC, with less archetypal variation than in Southern BC, fewer archetypes were used to represent them (Poirier et al., 2012). One storey homes of any construction date, located in a Northern climate zone, are separated in archetypes based on their HVAC energy source. The full list of housing archetypes and codes is included in Appendix A.

Table 4: Housing Archetype Characteristics

Climate zone	Construction Date	Storeys	HVAC	# of Archetypes
South Coastal (Vancouver)	Pre-1976	1	Natural Gas	16 combinations
Southern Interior (Summerland)	Post-1976	2	Electricity	
Northern (Prince George)	All	1	Natural Gas	4 combinations
Northern (Fort St-John)			Electricity	

Note: Adapted from Poirier et al. (2012)

[9] Though I did not have data on all of the home characteristics listed in the detailed Poirier et al. (2012) housing archetypes, the Energuide database did contain data on four characteristics that were not directly used in the simplified archetypes. These were a home's floor area, ceiling insulation, wall insulation, and air leakage values. The average value of each of these characteristics, for each simplified housing archetype group, matched or came close to matching the values used in the corresponding detailed Poirier et al. (2012) housing archetypes. This was taken as partial validation of the suitability of the simplified archetypes that I chose to use.

7.1.2 LiveSmart BC 3.0 and ecoENERGY Program Participation

I use the NRCan EnerGuide audit database to assess the quantity and characteristics of single-detached homes that were retrofitted in BC from April 1, 2011 to March 31, 2012 while the LiveSmart BC 3.0 and ecoENERGY EE programs were in operation. The NRCan EnerGuide audit database contains detailed energy audit information on over 95,000 homes across British Columbia. This data is collected by NRCan every time a household chooses to have a certified EnerGuide energy audit conducted on their home. Because a household must choose to have an energy audit performed on their home, the NRCan EnerGuide audit database may suffer from selection bias, and as a result the dwellings included in the audit database may not be representative of the provinces housing stock. Also, the types of households that commissioned the energy audits and performed retrofits on their homes may not be representative of BC's households.

The NRCan EnerGuide audit database is broken down into pre- and post-EE retrofit audits. I use the date of a home's pre-retrofit energy audit to estimate the date of EE measure uptake. I use pre-, instead of post-, retrofit audit dates for two reasons. First, the incentives available at the time of the pre-retrofit audit may have encouraged the audit to be undertaken by the household. And second, households which then went on to complete EE retrofits of their homes were only eligible to receive the incentives that had been available during the time of their pre-retrofit audit. A home's post-retrofit audit could be completed at a date well after the retrofit had been completed. The home energy audit data I received from NRCan only contained data on homes that had undergone both pre- and post-retrofit audits.

The period of April 1, 2011 to March 31, 2012 is highlighted in figure 3, and saw the retrofitting of 20,587 single detached homes, with an average pre-retrofit audit rate of 1,716 audits/month and an average household energy usage reduction of 26%. At the center of this period were five consecutive months in which the pre-retrofit audit rate averaged 2,580 audits/month with an average household energy usage reduction of 25%. The rate of heating fuel switching was quite low, with approximately 1% of households switching from natural gas to electrical heating systems during this period. The average monthly EE measure uptake and energy use reductions induced by these programs loosely resemble those deemed necessary by the Pembina Institute for BC to reach an 80-100% reduction of GHG emissions from the building sector by 2050 (Frappé-Sénéclauze & Heerema, 2016).

Not all single detached homes recorded in the EnerGuide database as having undergone EE retrofits during the selected period of 2011/12 fit into the housing archetypes I have chosen. The number of single detached homes from the 2011/12 period of the EnerGuide database that fit into my chosen housing archetypes is 17,986 homes. I use this value as the total number of homes that participate in the Subsidy Scenario, and the maximum number of homes that could participated in the Finance and Finance + Subsidy Scenarios. This is reasonably representative of the participation in the LiveSmart BC 3.0 and ecoENERGY EE programs as it represents the majority, 87%, of the homes retrofitted while these programs were in operation.

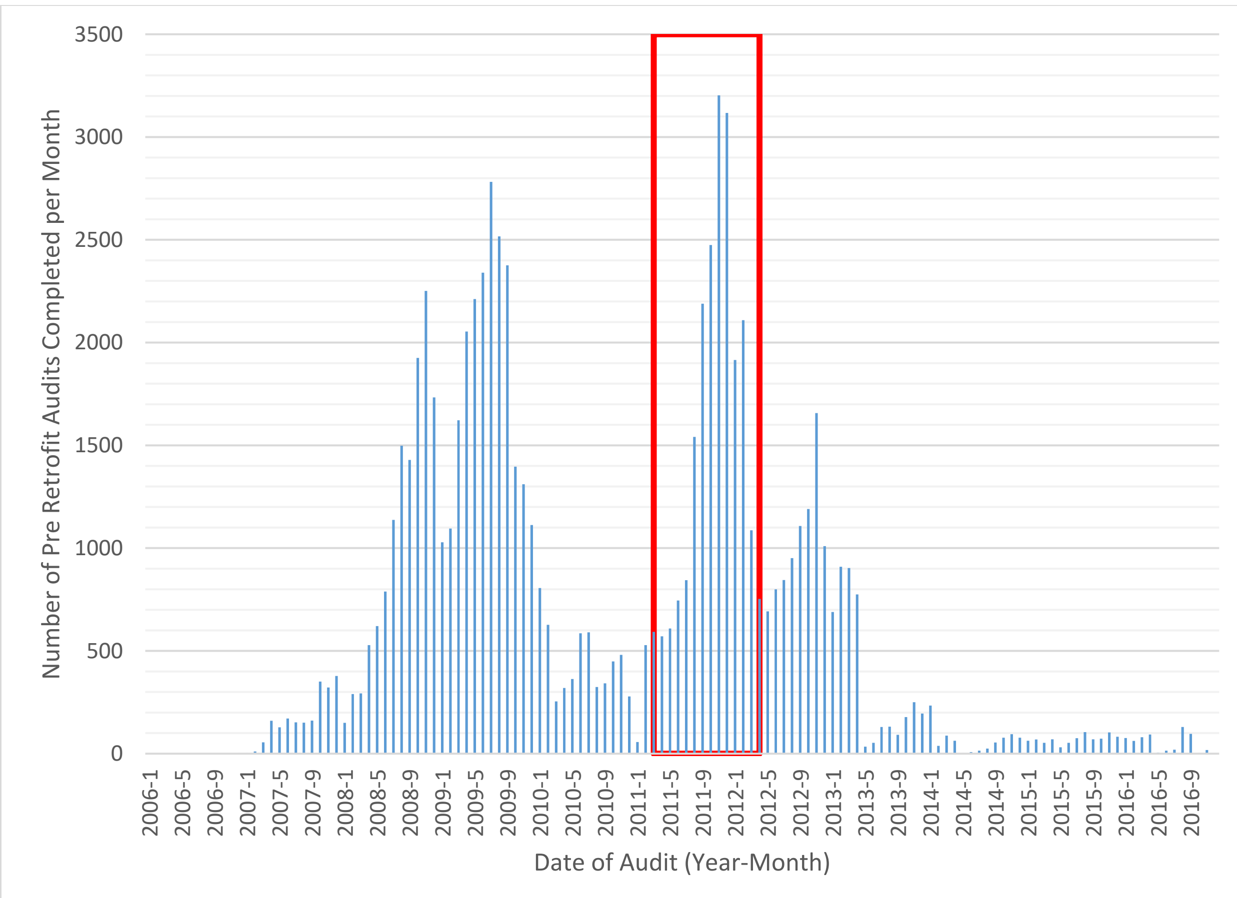

Figure 3: Number of EnerGuide Pre-Retrofit Audits of Single Detached BC Homes per Month (2006-2016). Adapted from Natural Resource Canada's EnerGuide Database.

In this paper, I assume that the homes recorded as having completed a post-retrofit audit in the NRCan EnerGuide audit database during the 2011/12 fiscal year, would have participated in both the LiveSmart BC 3.0 and ecoENERGY programs. This is a reasonable assumption because a major reason for the completion of a post-retrofit audit was to show what retrofits had been installed, and in turn, qualify for LiveSmart and ecoENERGY rebates. If a household was not expecting to receive a rebate there was very little incentive for them to commission a post-retrofit audit of their home. It seems highly likely that an eligible household would have received an EE measure rebate from both programs had they applied because originally the LiveSmart BC program was designed to compliment the ecoENERGY program (BC Hydro, 2013). I could not find separate program participation data for the LiveSmart and ecoENERGY programs. Program participation data presented by the BC Ministry of Energy and Mines Energy Efficiency Branch (2015) does not distinguish between participation in the LiveSmart and ecoENERGY programs. This may indicate that these programs operated so closely together that they could almost be considered one program.

All EE measure rebates included in the Subsidy Scenario match those provided by LiveSmart BC 3.0 and ecoENERGY. Due to data constraints, while the Subsidy Scenario model contains EE measure rebates from each of the EE measure categories present in the LiveSmart BC 3.0 and ecoENERGY programs, it contains fewer separate EE measure rebates than were historically available. I assume that a household which installed an EE measure from a certain EE measure category in the 2011/12 LiveSmart BC 3.0 and ecoENERGY programs, would be just as likely to install the same or different EE measure, from the same EE measure category, in my hypothetical Subsidy Scenario. This allows me to apply estimated LiveSmart BC 3.0 and ecoENERGY participation rates to the Subsidy Scenario. This assumption holds if a household's decision to invest in an EE measure was dependant on the availability of subsidies for EE measures in certain EE measure categories, rather than the EE measures themselves, and may lead to an overestimation of the participation rate in my Subsidy Scenario.

7.1.3 Energy Efficiency Measures

The 33 individual EE measures assessed in this paper are grouped into seven broad categories as follow: Basement/floor insulation, Attic insulation, Walls insulation, Draftproofing, Space

Heating (HVAC), Windows/Doors, and Domestic hot water heating. The approximate operational lifetimes of the EE measures considered were determined by speaking with professionals in the residential EE field. These can be found in Table 5.

The energy savings generated by each of the 33 different EE measures, when separately installed in each of the 20 housing archetypes used in this paper, were calculated by Poirier et al. (2012). Total capital costs of each EE measure were also sourced from Poirier et al. (2012) and checked against available historical data. From these total capital costs, I estimate EE measure incremental capital costs. The estimated incremental capital cost of each EE measure is used in the NPV calculations described below. Incremental capital costs are the extra costs that would need to be paid if a household were to invest in an EE measure instead of a comparable, yet less efficient, measure. An example of this is investing in a more expensive Energy Star certified furnace instead of investing in an uncertified, cheaper, and less efficient model. Only by investing incrementally more in an EE measure are energy bill savings generated. Therefore, it is correct to relate these incremental costs to the energy bill savings in the NPV calculations, instead of total EE measure capital cost. Maintenance costs are not considered in NPV calculations, and EE measure are assumed to maintain the same level of efficiency and produce the same energy savings through out their operating lifetimes. However, it may be the case that EE measure efficiency decreases over time, and by not taking this into account I may be overestimating future energy savings.

The 33 EE measures examined in this paper were all eligible for subsidies during the 2011/12 LiveSmart BC 3.0 and ecoENERGY programs. It is assumed that the total EE measure subsidy received by a household for the uptake of said EE measure equals the sum of the applicable subsidies available from both the LiveSmart and ecoENERGY programs.

Along with the EE measure operational lifetimes in Table 5, are the mean incremental capital cost of, and mean subsidy made available for, each EE measure category assessed in this paper. The complete list of EE measures and subsidies used in my analysis are shown in Appendix A.

Table 5: EE Measure Category Operational Lifetimes, Mean Costs, and Mean Subsidies

EE Measure Category	Lifetime (Years)	Mean Incremental Capital Costs	Mean Subsidies
Basement/floor Insulation	30	$6,719	$1,048
Attic Insulation	30	$994	$792
Walls Insulation	30	$1,843	$2,735
Draftproofing	30	$1,730	$981
Space Heating, Electric (HVAC)	20	$14,500	$4,188
Space Heating, Natural Gas (HVAC)	20	$750	$1,320
Windows/Doors	30	$11,043	$89
Domestic hot water (tankless)	20	$2,730	$668
Domestic hot water (storage tank)	12	$2,070	$438

Looking at Table 5 it is interesting to note that the mean subsidies available for both wall insulation and natural gas HVAC systems are larger than the mean incremental capital costs for both EE measure categories. These large subsidies may influence the NPV of these EE measure categories as we will see in the results section of this paper.

7.1.4 Using Net Present Value to Estimate Measure Uptake

I use the NPV of each EE measure/archetype combination as a means of estimating the EE measure uptake by rational households participating in one of the hypothetical finance based scenarios, relative to EE measure uptake estimated under the Subsidy Scenario. The EE measure NPVs calculated for the Subsidy Scenario are used as the control against which the Finance and Finance + Subsidy Scenarios were compared.

Net Present Value Calculations

I calculate the NPV of each combination of EE measure and archetype for each of the three-different hypothetical EE program scenarios. I also calculate a fourth set of NPVs under the assumption that no EE program was available and households were required to pay the full incremental capital cost of the EE measure out of pocket. The three EE program scenarios are:

1. Subsidies Scenario – historical LiveSmart BC 3.0 and ecoENERGY subsidies are applied to the EE measure incremental capital costs. This is the base case against which the two-hypothetical finance based EE scenarios are compared. The Subsidy Scenario energy

efficiency program only operates during the year 2011 (year zero). All subsidies are distributed in year zero.

2. Finance Scenario – EE measure incremental capital costs are completely paid for with financing alone. All financing is initially provided in 2011 (year zero), with annual interest payments beginning in year zero. The Finance Scenario program operates until all loans have been repaid.
3. Finance + Subsidy Scenario – EE measure incremental capital costs are paid for through a combination of financing and minor subsidies. All subsidies are distributed, and all financing is initially provided, in 2011 (year zero). Annual interest payments begin in year zero and the Finance + Subsidy Scenario program operates until all loans have been repaid.

As described earlier, I assume that EE measure uptake in the Subsidy Scenario is the same as the uptake assumed to have been induced by the LiveSmart BC 3.0 and ecoENERGY programs. I then use the calculated EE measure NPVs to estimate and compare the number of EE measures that may be installed by households if either the Finance or Finance + Subsidy Scenarios are used in place of the Subsidy Scenario. I assume that for measure uptake to remain the same in the hypothetical financing programs as it is in the Subsidy Scenario, that the NPV of each EE measure and archetype combination must retain the same mathematical sign (NPV>=0, NPV<0) as the corresponding Subsidy Scenario measure NPV. This simplifying assumption is necessary because the exact effect that changes to an EE measure's NPV may have on the measure's uptake is unknown.

The equation I use in the calculation of NPV is as follows:

$$NPV = \sum_{t=0}^{T} \frac{(E_t - L_t)}{(1+r)^t} + S - C$$

T: Total lifetime of a retrofit -1 (years)
t: Time period, 0 -> T (years)
E: Annual energy bill savings ($)
L: Annual loan repayment ($)
r: Consumer discount rate of 30% (%)
S: Subsidy value ($)
C: Remaining incremental capital cost paid by the consumer

Energy Prices

To calculate the value of EE measure induced energy savings I use the historical and predicted future prices of BC energy in the individual EE measure NPV calculations. The two energy sources considered in my analysis are electricity and natural gas. All geographic areas covered within this paper are subject to BC Hydro's two step residential electricity rates and FortisBC's natural gas rates. BC Hydro's two step electricity rates are made up of an initial $/kWh rate for the first 1,350 kWh used per billing period, and a second higher rate for all electricity used above 1,350 kWh per billing period. Historical electricity rates were sourced from BC Hydro's annual rate schedule 1101 and energy bills dating back to 2011 (BC Hydro, 2017b). Fortis BC natural gas bills provided historical data on natural gas delivery, storage & transport, commodity, and tax rates for residential natural gas consumers through out the province.

Future electricity rates were generated with the use of the provincial government's 10-year plan which will run until the fiscal year 2024 (F2024). Hence, electricity rates are assumed to increase at a rate of 3% from F2020 to F2024, and 2% per year after F2024. Future natural gas rate predictions were generated by GLJ Petroleum Consultants (GLJPC) up until 2026 (GLJ Petroleum Consultants, 2017). After 2026 it was assumed that the cost of natural gas would escalate at a rate of 2% per year as indicated by GLJPC's estimates.

When energy prices are used in the NPV calculations above, they are applied to the energy savings generated by an EE measure. For simplicity, only step one electricity rates are applied to the energy savings in homes with a natural gas fueled heating system, and only step two electricity rates are applied to the energy savings in homes with electrical heating systems. This is justified with a comparison of the annual EE measure induced energy savings of natural gas and electrically heated homes, with the average annual electricity consumption for similarly heated single detached BC homes found in the BC Hydro 2014 Residential End Use Survey (BC Hydro, 2015).

Energy bill savings are calculated on an annual basis with the use of average monthly or bi-monthly energy bill savings.[10] This is done to better facilitate the calculation of an EE measure's NPV as discussed in the following section. To give an idea of BC energy prices, Table 6 shows annual

[10] Residential energy use in BC is largely dependant on seasonal temperature changes. Because of this, residential energy consumption changes through out the year and may differ between winter and summer months. For simplicity, a typical BC household's average bi monthly energy consumption in a year was used.

energy prices in $/GJ for both electricity and natural gas from 2011 to 2018, along with the predicted 2041 prices. Though electricity is typically billed in $/kWh, I have converted it to $/GJ for ease of comparison.

Table 6: Annual Energy Prices in BC 2011-2018, and 2041

Fuel Type		2011	2012	2013	2014	2015	2016	2017	2018	…….	2041
Electricity ($/GJ)	Step 1	$21.27	$21.27	$21.13	$23.03	$24.41	$25.39	$26.28	$27.07	…….	$43.96
	Step 2	$30.68	$30.68	$31.67	$34.51	$36.60	$38.07	$39.41	$40.58	…….	$65.92
Natural Gas ($/GJ)		$10.95	$10.28	$9.81	$11.56	$10.69	$8.93	$9.11	$9.67	…….	$13.04

Interest Rate of Loans

The annual interest rate I use in my loan repayment calculations is 4%. The funds used in my hypothetical 2011/12 EE Financing Scenarios are to be leant out by the provincial government. These funds would likely need to be borrowed by the provincial government. Canada's 2011/12 prime lending rate was 3.0% and represents the interest rate at which the provincial government could likely have borrowed funds in 2011 (Bank of Canada, 2017). To encourage program participation, the provincial government could then lend these funds out at, or close to, the interest rate at which they were borrowed. Therefore, I use an annual interest rate of 4% in the calculation of a household's monthly loan repayments. This is made up of Canada's 2011/2012 prime lending rate of 3.0%, plus a 1% administrative cost recovery measure. This administrative cost recovery measure is in line with financing programs currently being operated by Manitoba Hydro and will be discussed further in the EE program scenario cost section of this paper. It should be noted that for simplicity I use a fixed annual rate of interest over the entire loan amortization period. The amortization period in this case being the operating lifetime of a loan's respective EE measure. In reality, it is not unusual for a loan's interest rate to be renegotiated after a predetermined number of years. This adds an element of unpredictability not accounted for in this model.

This 4% annual interest rate is a reasonable lending rate that could have been offered by an EE financing program in 2011/12. It is also similar to the lending rate currently available to City of Nelson EcoSave program participants. The calculated monthly loan repayments are summed into an annual loan repayment, which is discounted annually along with induced energy bill savings in the NPV calculation. The same annual interest rate is used in both the Finance and Finance + Subsidy Scenarios.

Discount Rate

Previous literature shows that consumers place high discount rates on permanent residential EE measures ranging from 25-36% (Sanstad et al., 2006). Based on this literature I use a consumer discount rate of 30% in my NPV calculations.

NPV Calculation for Finance Scenarios

Finance Scenario NPV

The Finance Scenario NPV calculation assumes that the EE measure financing is paid back over the entire operational lifetime of the EE measure, and that financing is the only means by which EE measure incremental capital costs are paid for.

Finance + Subsidy Scenario NPV

The Finance + Subsidy Scenario NPV calculation is built off of the Finance Scenario NPV. Finance Scenario NPVs which have a different sign than their corresponding Subsidy Scenario NPV are adjusted upward by applying subsidies to the EE measure's incremental capital cost until the sign of the measure's Finance + Subsidy Scenario NPV match that of the measure's Subsidy NPV.

7.1.5 Assessing total EE measure uptake and program cost

Measure Uptake

Data on the number of EE retrofits per EE measure category, performed through LiveSmart BC 3.0 and ecoENERGY programs, is available in BC Ministry of Energy and Mines Energy Efficiency Branch (2015). But data on the number of different types of individual EE measures installed in the province is not available, and thus must be estimated.

The dataset I use from Poirier et al. (2012) provides all energy savings estimates, capital costs, and in turn my NPV calculations, for their corresponding individual EE measure/archetype combinations. Each individual EE measure/archetype combination represents the installation of one of the 33 individual EE measures into one of the 20 housing archetypes. By estimating the maximum number of homes in each individual EE measure/archetype combination that can participate in each hypothetical EE program scenario, I in turn estimate the total number of different types of individual EE measures that might be expected to be installed under each scenario.

For each individual EE measure/archetype combination presented in the Poirier et al. (2012) dataset is an estimate of the percent of homes that will install their individual EE measure, given that they have had work done in the EE measure's category.[11] This percent can be used to estimate the maximum number of homes in each individual EE measure/archetype combination that can participate in a hypothetical EE program scenario by doing the following:

1. From the maximum of 17,986 homes that can participate in the hypothetical EE program scenarios, determine the number of homes in each housing archetype.

$$\mathbf{17,986}\ homes \times \mathbf{16.69}\%\ of\ homes\ in\ archetype\ \#111 =$$
$$\mathbf{3002}\ archetype\ \#111^{12}\ homes$$

2. Multiply the number of homes in each housing archetype by the estimated percentage of homes that will have work done in a certain EE measure category. These percentages are sourced from table D-4 in the retrofit program review completed by the BC Ministry of Energy and Mines, Energy Efficiency Branch (2015). The resulting values are the number of homes in each archetype that will have work done in a certain EE measure category.

$$\mathbf{3002}\ archetype\ \#111\ homes \times \mathbf{39.08}\%\ of\ homes\ in\ draftproofing\ category$$
$$= \mathbf{1173}\ archetype\ \#111\ homes\ with\ draftproofing\ work$$

3. For each EE measure/archetype combination, multiply the estimated number of homes in its certain archetype that will have work done in its certain EE measure category, by the

[11] It is unclear how Poirier et al. (2012) estimated these percentages.
[12] Housing archetype codes are defined in Appendix A.

percent of homes that will install this individual EE measure, given that they have had work done in the EE measure's category, sourced from Poirier et al. (2012).

$$\mathbf{1173}\ archetype\ \#111\ homes\ with\ draftproofing \times$$
$$\mathbf{50}\%\ of\ homes\ installing\ the\ air\ sealing\ (target + 5\%)\ EE\ measure =$$
$$\mathbf{587}\ \text{homes}$$

This results in an estimate of the maximum number of homes in each individual EE measure/archetype combination that can participate in each hypothetical EE program scenario. Because only one individual EE measure is installed per home in an individual EE measure/archetype combination, this can also be interpreted as the maximum number of individual EE measures in each individual EE measure/archetype combination that can be installed in each hypothetical EE program scenario.[13]

Table 7 below shows a portion of the data table I use to make these calculations. This shows the estimated number archetype #111 homes (pre-1976, one-storey, Natural Gas, South Coastal (Vancouver)) that would have installed individual EE draftproofing measures under the hypothetical Subsidy Scenario. This and other archetype descriptions and codes are located in Appendix A.

[13] A home may receive multiple EE measures from the same EE measure category, but can only receive one of each individual EE measure.

Table 7: Number of Individual Measures Installed Per Measure/Archetype Combination

Retrofit Category	Individual EE Measure	Maximum # of Homes in the Program	Share of Homes in Archetype [14]	Share of Homes in Measure Category [15]	Share of Homes installing Individual Measure [16]	Number of Homes Which Installed an Individual Measure Per Measure/Archetype Combination
Draftproofing	Air sealing, target +5%	17,986	16.69%	39.08%	50.00%	586.58
Draftproofing	Air sealing, target +15%	17,986	16.69%	39.08%	35.00%	410.61
Draftproofing	Air sealing, target +25%	17,986	16.69%	39.08%	14.00%	164.24
Draftproofing	Air sealing with HVI certified HRV installed	17,986	16.69%	39.08%	1.00%	11.73

As all 17,986 homes are assumed to participate in the Subsidy Scenario, the maximum number of estimated EE measures are assumed to be up taken during the Subsidy Scenario. The sign of each individual EE measure/archetype combination NPV is used to determine which individual EE measure/archetype combinations experience uptake during the Finance and Finance + Subsidy Scenarios. If an individual EE measure/archetype combination in the Finance Scenario has a negative NPV while it has a positive NPV in the Subsidy Scenario, it is assumed that no uptake of this individual EE measure/archetype combination will occur in the Finance Scenario. My model is limited in that the number of homes able to participate in the finance based scenarios cannot exceed 17,986. Because of this, estimated EE measure uptake in the finance based scenarios will never exceed EE measure uptake in the Subsidy Scenario.

Once the province wide number of homes that will install individual EE measures has been estimated for each EE program scenario, it is then possible to sum the total value of their corresponding incremental capital costs, subsidies, and financing to produce an estimated total program cost. These different program costs are then compared.

[14] The share of houses in each archetype was calculated with the use of the NRCan EnerGuide Home Energy Audit database.
[15] The share of houses in each measure category (Basement/floor, Attic, Walls, Draftproofing, Space Heating (HVAC), Windows/Doors, and Domestic hot water) was calculated with the use of BC MEM’s 2015 report "A Review of Whole Home Energy Retrofit Programs in British Columbia from 2007-2015".
[16] For some measure categories, this column does not sum to 100%. This is because in some cases one home may have multiple individual measures of the same measure category installed in it.

EE Program Scenario Cost

When calculating the total program operating cost of providing the three hypothetical EE program scenarios, two main cost categories are considered: the cost of subsidies provided, and the administrative cost of operating the program. Administrative costs are assumed to include such things as program design, start up, advertising, and day to day program operation. The program operating cost of the Subsidy Scenario is composed of both subsidy provision, and administrative costs, whereas the program operating cost of the EE finance based programs is only composed of administrative costs.

As stated above, all uptake induced by each EE program scenario is assumed to take place within the first year of program operation. It is also assumed that subsidies and financing are only distributed to eligible households during this first year. Because of this, the Subsidy Scenario program only operates for one year, incurring all program operating costs in 2011, and ending at the end of the year once all subsidies have been distributed. Unlike the Subsidy Scenario program that only operates for one year, the finance based EE programs must remain in operation for the lifetime of the loans initially provided. They do not incur all program operating costs in year one, and instead distribute their operating costs over the lifetimes of the loans provided. This is because, in addition to program start up costs, loan repayments must be managed each year, interest rates may need to be renegotiated, and possible loan defaults must be dealt with if they arise.

The PV of administrative costs for the Subsidy Scenario are estimated from the FortisBC Natural Gas Demand-Side-Management (DSM) Programs 2015 Annual report. When providing residential EE subsidies in 2015, FortisBC found that 17.3% of their total annual expenditures were on non-incentives spending (FortisBC, 2016).[17] For the purpose of this paper I refer to non-incentives spending as a program's administrative cost. From the results of FortisBC (2016) I assume that administrative costs are 17.3% of the total subsidy program cost. Note that it is unknown whether this share of administrative costs, sourced from FortisBC (2016), is representative of all subsidy based programs, and may in fact differ between programs.

[17] Note: The FortisBC residential natural gas DSM program costs are used over the FortisBC residential electricity DSM program costs as their natural gas DSM program is approximately 12 times larger by total program spending than their electricity DSM program. Due to its larger size, the natural gas DSM program is assumed to be more relevant to this study.

The equation I use to determine the PV of administrative costs for the Subsidy Scenario from the total dollar amount of subsidies provided is shown below. No discounting is required as all program costs are incurred immediately.

$$Subsidy\ Scenario\ Admin\ Cost\ (\$) = \frac{Subsidies\ Provided\ (\$)}{0.827} * 0.173$$

In this equation, I assume that administrative costs make up 17.3% of the total program cost, and that the subsidies themselves make up the remaining 82.7%. Having estimated the dollar value of the subsidies provided I divide this by 0.827 to find the estimated total program operating cost. This total program operating cost is then multiplied by 0.173 to give the estimated administrative cost of the program.

Similarly, the PV of a financing based EE program's total administrative cost must be estimated. In this case Manitoba Hydro's EE financing programs are used as a proxy. Their financing programs incorporate administrative cost recovery fees into the interest rates of their loans. These administrative costs can make up one to three percentage points of the total annual interest rate applied to a loan (B. Radtke, personal communication, February 21, 2017). In this paper, I assume that this could be emulated in a BC financing program. Of the 4% interest rate used in the Finance and Finance + Subsidy Scenarios, I assume that three percentage points are applied to the cost of originally borrowing the funds at the Canadian prime interest rate, incurred by the provincial government, and the remaining one percentage point is applied to administrative costs. This means that one quarter of the annual interest earned on an EE measure loan is allocated to administrative costs. The process I use to calculate the PV of a financing program's total administrative cost is the same for both the Finance and Finance + Subsidy Scenarios. I first calculate the annual total amount of interest to be collected by the provincial government, from all borrowers, in every year that loans are to be repaid. As a loan amortization period equals the lifetime of its respective EE measure, loan repayments are made for a maximum of 30 years. I then allocate one quarter of each annual total program interest repayment towards administrative costs, giving an annual program administrative cost for each year of repayment. The PV of a financing program's total administrative cost is then calculated by discounting this stream of annual program administrative costs, to be collected/incurred over the next 30 years, at a discount rate of 3%. I use a discount rate of 3% to represent the provincial government's time value of money. In 2011 this was the Canadian prime lending rate, and it is reasonable to expect that the provincial government could lend money at this rate should it choose to.

The equation used to determine the PV of a financing based EE program's total administrative cost is shown below.

$$PV\ Admin\ Cost\ (\$) = \sum_{t=0}^{29} \frac{A_t}{(1.03)^t}$$

A: Annual program administrative cost ($)
t: Time period, 0 -> T (years)

7.2 Results

In the following sections I discuss the results of my analysis. I begin by reporting the calculated EE program scenario NPV statistics and assessing which EE measure categories and program scenarios may be most economically beneficial to households. This data is divided by a home's primary heating fuel, electricity and natural gas. I make this division by energy source because a home's heating fuel is directly linked to a household's energy consumption, and it shows the important effect that a home's primary heating fuel can have on prospective EE measure NPVs.

This is followed by estimates of EE measure uptake by measure category given the EE program scenario that is available. This allows us to compare the estimated uptake between scenarios, and then move on to the estimated cost of these scenarios. I end by examining the efficiency of each scenario in terms of their estimated dollars spent per unit energy and GHG reduction.

7.2.1 NPV Statistics

Table 8 and Table 9 show the percent of positive EE measure NPVs in each measure category, for each EE program type, when installed into homes where the primary heating fuel is electricity or natural gas respectively. These values show what proportion of EE measures in each measure category, when installed in the various housing archetypes, result in a positive NPV. This indicates what percentage of the EE measures in each category could warrant investment by a household.

Only 25 individual EE measure/archetype combinations resulted in a positive NPV under the Subside Scenario while having a negative NPV under the Finance Scenario. Therefore, only these 25 individual EE measure/archetype combinations received subsidies under the Finance + Subsidy Scenario, to the point where their NPV would become positive. The rest of the individual EE measure/archetype combination NPVs remained the same under the Finance + Subsidy Scenario as under the Finance Scenario. For this reason, the percent of positive NPVs per measure category in the Finance + Subsidy Scenario is either equal to, or great than, the percent of positive NPVs per measure category in the Finance Scenario.

In general, a greater proportion of EE measures have positive NPVs when installed into homes that have electricity as their primary heating fuel. The main exception being space heating, where 100% of the natural gas furnace upgrades under each of the three EE program scenarios have a positive NPV. In the Subsidy and Finance + Subsidy Scenarios, wall insulation always has a positive NPV. This is likely due in large part to the very high level of subsidies available for wall insulation measures. This is good for households, but may represent overspending by the administering organization.

Table 8: Electrically Heated Homes, Percent of EE Measures with Positive NPV by Measure Category and Program Type

	Percent of Positive NPV's by Scenario			
Measure Category	**Full Capital Cost**	**Subsidy**	**Finance**	**Finance + Subsidy**
Basement/floor	29.41%	29.41%	35.29%	35.29%
Attic	28.57%	71.43%	92.86%	92.86%
Walls	50.00%	100.00%	100.00%	100.00%
Draftproofing	30.00%	70.00%	80.00%	80.00%
Space Heating (HVAC): Fuel Source Elec to Elec	30.00%	40.00%	76.67%	76.67%
Windows/Doors	0.00%	0.00%	25.00%	25.00%
Domestic hot water	3.03%	15.15%	16.67%	19.70%

In electrically heated homes, every wall insulation measure within an EE program scenario has a positive NPV. The majority of attic, draftproofing, and space heater upgrades also have positive NPVs.

Table 9: Natural Gas Heated Homes, Percent of EE Measures with Positive NPV by Measure Category and Scenario

	Percent of Positive NPV's by Scenario			
Measure Category	**Full Capital Cost**	**Subsidy**	**Finance**	**Finance + Subsidy**
Basement/floor	17.65%	29.41%	29.41%	29.41%
Attic	0.00%	53.33%	46.67%	53.33%
Walls	22.86%	100.00%	71.43%	100.00%
Draftproofing	2.50%	37.50%	52.50%	55.00%
Space Heating (HVAC): Fuel Source NG to NG	80.00%	100.00%	100.00%	100.00%
Space Heating (HVAC): Fuel Source NG to Elec	0.00%	0.00%	0.00%	0.00%
Windows/Doors	0.00%	0.00%	0.00%	0.00%
Domestic hot water	3.03%	15.15%	16.67%	19.70%

In natural gas heated homes, a large proportion of attic and wall insulation measures have positive NPVs. It is interesting to note that though all natural gas furnace upgrades have a positive NPV, none of the natural gas furnace to electric heater conversions (NG to Elec) have a positive NPV. This is due to the incremental capital cost of the EE measures in question, and the changes to energy consumption that they induce. The incremental capital cost of electric heating systems such as air source heat pumps (ASHP) and ground source heat pumps (GSHP) are much greater than those of EE natural gas furnaces. In addition, converting from a natural gas to electric heating systems results in reduced natural gas consumption, but increased electricity consumption. Because electricity rates are much higher than natural gas rates, the cost of this increase in electricity consumption can negate any natural gas energy bill savings.

None of the window and door measures installed into natural gas heated homes have a positive NPV. This is due to their high incremental capital cost, low to moderate induced energy consumption reduction, and low natural gas rates for natural gas heated homes. The number of windows assumed to be replaced in each home varies between housing archetypes, and ranges from 16 to 22 windows per home. The number of doors assumed to be installed also varies, from 2-3 per home.

The mean and median EE measure NPV are shown in Table 10 and Table 11 by measure category and EE program scenario, when installed into homes where the primary heating fuel is electricity or natural gas respectively. By comparing these two tables we can see that on average, EE measures installed in electrically heated homes result in a greater NPV than if they were installed in natural gas heated homes. There are also differences in measure category NPVs across program types. The EE measure category average NPVs are lowest when households must pay the full capital cost of the measures themselves. It is interesting to note that the average NPV of electric space heating systems is negative under the Subsidy Scenario, while it is positive under the Finance and Finance + Subsidy Scenarios. This is because some electric space heating systems experience a negative NPV in the Subsidy Scenario due to the very high, after rebate, initial cost of the measure, while the same measure when its initial capital cost is financed, manages to maintain a positive NPV due to increasing electricity rates over time.

Table 10: Electrically Heated Homes, Average NPV of EE Measures by Category and Scenario

Measure Category	Scenario NPV							
	Full Capital Cost		Subsidy		Finance		Finance + Subsidy	
	Mean	Median	Mean	Median	Mean	Median	Mean	Median
Basement/floor	-$5,726	-$8,606	-$4,551	-$6,936	-$661	-$823	-$661	-$823
Attic	-$150	-$443	$690	$290	$608	$258	$608	$258
Walls	$1,027	-$7	$3,755	$2,869	$2,417	$1,008	$2,417	$1,008
Draftproofing	-$766	-$373	$227	$219	$539	$358	$539	$358
Space Heating (HVAC): Fuel Source Elec to Elec	-$6,730	-$1,544	-$3,908	-$202	$54	$567	$54	$567
Windows/Doors	-$8,807	-$7,833	-$8,717	-$7,743	-$480	-$383	-$480	-$383
Domestic hot water	-$2,023	-$1,799	-$1,393	-$1,418	-$405	-$506	-$405	-$506

Table 11: Natural Gas Heated Homes, Average NPV of EE Measures by Category and Scenario

Measure Category	Scenario NPV							
	Full Capital Cost		Subsidy		Finance		Finance + Subsidy	
	Mean	Median	Mean	Median	Mean	Median	Mean	Median
Basement/floor	-$6,319	-$9,840	-$5,143	-$8,004	-$1,253	-$1,845	-$1,253	-$1,845
Attic	-$602	-$620	$198	$15	$140	-$13	$142	$0
Walls	-$668	-$555	$2,059	$2,084	$722	$163	$750	$163
Draftproofing	-$1,352	-$651	-$360	-$83	-$48	$4	-$46	$4
Space Heating (HVAC): Fuel Source NG to NG	$470	$294	$1,800	$1,663	$987	$886	$987	$886
Space Heating (HVAC): Fuel Source NG to Elec	-$14,930	-$15,066	-$10,742	-$10,878	-$4,946	-$5,082	-$4,946	-$5,082
Windows/Doors	-$10,085	-$9,722	-$9,996	-$9,632	-$1,759	-$1,440	-$1,759	-$1,440
Domestic hot water	-$10,085	-$1,900	-$1,467	-$1,495	-$479	-$589	-$478	-$589

7.2.2 EE Measure Uptake

The estimated EE measure uptake per measure category and EE program scenario is shown in Table 12. This shows the estimated number of individual EE measures that may be installed by households across the province depending on which of the three hypothetical EE scenarios was in place at the time. The estimated EE measure uptake induced by the Subsidy Scenario is used as the base case against which the hypothetical Finance, and Finance + Subsidy Scenarios are compared. I check my Subsidy Scenario uptake estimates against data collected by the BC Ministry of Energy and Mines, Energy Efficiency Branch (2015) from the 2011/12 LiveSmart BC and ecoENERGY programs. As can be seen in Table 12, my estimates match closely to data found in the BC Ministry of Energy and Mines, Energy Efficiency Branch (2015) report on whole home energy retrofit programs in BC. This does not completely validate my estimates, but does show them to be within the realm of possibility.

Discrepancies in the estimated EE measure uptake between data from the 2011/12 LiveSmart BC and ecoENERGY programs, and the three hypothetical EE scenarios, are primarily due to the way I calculate EE measure uptake. As stated earlier, the EE measure uptake calculations use estimates by Poirier et al. (2012) on the percent of homes that will install an individual EE measure, given that they have had work done in the EE measure's category. These estimated percentages may overstate and/or understate EE measure uptake within EE measure categories.

Table 12: Estimated EE Measure Uptake by Program Type and Measure Category

		EE Measure Uptake by Scenario		
Measure Category	**LiveSmartBC 3.0 & ecoENERGY (2011/12) Uptake**	**Subsidy**	**Finance**	**Finance + Subsidy**
Basement/floor	2,649	4,628	4,628	4,628
Attic	4,823	4,553	4,462	4,553
Walls	932	1,844	956	1,844
Draftproofing	7,284	7,029	6,977	7,029
Space Heating (HVAC)	13,237	12,753	12,753	12,753
Windows/Doors	9,563	8,088	8,088	8,088
Domestic hot water	785	817	817	817
Totals	**39,273**	**39,713**	**38,681**	**39,713**

Note: Data for LiveSmartBC 3.0 & ecoENERGY (2011/12) Uptake from BC Ministry of Energy and Mines Energy Efficiency Branch, (2015) From a consumer perspective, under the Finance Scenario, some of the resulting EE measure NPVs in the attic and wall insulation, and draftproofing EE measure categories are negative while being positive in the Subsidies Scenario, and therefore the model shows a reduced EE measure uptake under the Finance Scenario as compared to uptake under the Subsidy Scenario. This can be seen by comparing the Subsidy and Finance columns of Table 12. Applying subsidies to a financed measure can increase its NPV. In the case when an EE measure's NPV is positive under the Subsidy Scenario, but negative under the Finance Scenario, subsidies are applied to the EE measure in the Finance Scenario until the measures' NPV becomes zero, matching the positive sign it received under the Subsidy Scenario. Doing this increases the estimated measure uptake of the Finance Scenario to match that of the Subsidy Scenario as can be seen in the Finance + Subsidy column of Table 12. In this model, EE measure uptake in the Finance and Finance + Subsidy Scenarios will not exceed uptake in the Subsidy Scenario due to the way the model is constructed. EE measure uptake in the Finance and Finance + Subsidy Scenarios are based on EE measure uptake in the Subsidy Scenario. Hence total estimated uptake in the Finance + Subsidy Scenario is equal to the total estimated uptake in the Subsidy Scenario.

By comparing EE measure uptake in Table 12 with the percent of positive EE measure NPVs in Table 8 and Table 9, the model shows that many EE measures with a negative NPV were installed during the Subsidy Scenario, and in turn, the Finance and Finance + Subsidy Scenarios. This does not necessarily mean that households are acting irrationally. This may indicate that there are factors other than NPV influencing a household's decision to invest in EE measures. For example, a household may choose to install new EE windows and doors for their aesthetic appeal, rather than for the limited energy savings they may provide. This may also be due to free riders participating in the subsidy program. A household may be replacing their windows and doors out of necessity and simply choose to participate in the subsidy program because it is available. Alternatively, the apparent uptake of EE measures with a negative NPV may be due to the choice of specific measure uptake estimates in my calculations.

7.2.3 Program Cost and Efficiency

I will now report the estimated total program operating cost and efficiency of the three hypothetical EE program scenarios.

Subsidy Scenario

The total operating cost of the Subsidy Scenario is made up of administrative costs and the cost of the subsidies provided to households. The Subsidy Scenario program only operates for one year, and all of its operating costs occur within this year. The model estimates that the subsidies provided by the Subsidy Scenario would total $33.1 million[18].

Using FortisBC's subsidy programs as an example it is assumed that administrative costs make up 17.3% of a subsidy program's total cost. Applying this to the subsidy cost estimates made for the Subsidy Scenario yields an estimated administrative cost of $6.9 million. This brings the estimated total cost of operating the Subsidy Scenario program to $40 million. This seems like a reasonable total cost estimate when compared to FortisBC's smaller 2015 DSM program that cost $31.9 million (FortisBC, 2016).

I estimate that the EE measures installed under the Subsidy Scenario result in a total energy use reduction of 14.2PJ and a GHG emissions reduction of 657,022 tonnes CO2e over their operational lifetimes. The efficiency of the Subsidy Scenario in terms of program dollars spent per unit energy and GHG reduction is shown in Table 13.

Table 13: Subsidy Scenario Program Operating Cost and Efficiency

Retrofit Category	Program Operating Cost ($)	Program Operating Cost per unit Energy Reduction ($/GJ)	Program Operating Cost per unit GHG Reduction ($/tonne CO2e)
Basement/floor	$5,959,000	$5	$130
Attic	$3,546,000	$6	$130
Walls	$5,697,000	$11	$270
Draftproofing	$4,151,000	$3	$80
Space Heating (HVAC)	$19,246,000	$3	$60
Windows/Doors	$848,000	$0.19	$5
Domestic hot water	$524,000	$6	$110
Total Program	**$39,971,000**	**$3**	**$60**

Note: Dollars spent in the Subsidy Scenario are only composed of subsidies and administrative costs

[18] This may differ from the actual amount that was provided by these programs. It was difficult to find exact numbers on the total dollar amount of subsidies provided through the LiveSMart BC 3.0 and ecoENERGY programs in 2011/12 as reports on these programs did not specifically break down annual program costs. That being said, as this is a comparison of estimated program costs the information generated here is still of importance on a relative cost basis.

Finance Scenario

With no subsidies on offer in the Finance Scenario, only the administrative costs of providing the financing are considered. As described earlier, by using Manitoba Hydro's financing programs as an example, it is assumed that the administrative cost of providing financing in the hypothetical Finance Scenario would be incorporated as 1% percentage point of the 4% interest rate on a household's EE measure loan.

The total estimated amount of financing made available in the form of EE measure loans in the first year of the Finance Scenario is $149 million. From this, the estimated Finance Scenario administrative cost paid by the provincial government in the first year of the finance program is $2.2 million. As loans reach their maturity date the annual administrative costs decrease, until reaching $801,276, thirty years later, in 2040 when the last loans are paid off completely. The estimated PV of the Finance Scenario's annual administrative costs is $43 million.

I estimate that the installed EE measures result in a total energy use reduction of 14PJ and a GHG emissions reduction of 644,357 tonnes CO2e over their operational lifetimes. The efficiency of the Subsidy Scenario in terms of program dollars spent per unit energy and GHG reduction is shown in Table 14.

Table 14: Finance Scenario Program Operating Cost and Efficiency

Retrofit Category	Program Operating Cost ($)	Program Operating Cost per unit Energy Reduction ($/GJ)	Program Operating Cost per unit GHG Reduction ($/tonne CO2e)
Basement/floor	$8,139,000	$7	$179
Attic	$1,158,000	$2	$45
Walls	$405000	$2	$43
Draftproofing	$1,674,000	$1	$31
Space Heating (HVAC)	$3,940,000	$1	$12
Windows/Doors	$26,744,000	$6	$147
Domestic hot water	$555,000	$6	$121
Total Program	**$42,615,000**	**$3**	**$66**

Note: Dollars spent in the Finance Scenario are only composed of administrative costs

Finance + Subsidy Scenario

The operating costs of the Finance + Subsidy Scenario are made up of a combination of the subsidies provided to households, the administrative cost of distributing these subsidies, and the administrative cost of providing financing. Both subsidy and financing administrative costs are calculated in the same manner as was done in the previous two scenarios.

The subsides provided under this scenario are calculated to total approximately $481,874. From this I estimate that the administrative costs of providing these subsides would be $100,803, resulting in a total subsidy program cost of approximately $582,677. The total estimated amount of financing made available in the form of EE measure loans in the first year of the Financing + Subsidy Scenario is $151 million. From this, the estimated Financing + Subsidy Scenario administrative cost paid by the provincial government in the first year of the finance program is $2.2 million. As loans reach their maturity date the annual administrative costs decrease, until reaching $810,935, thirty years later, in 2040 when the last loans are paid off completely. The estimated PV of the Financing + Subsidy Scenario's annual administrative costs is $44 million.

I estimate that the installed EE measures result in a total energy use reduction of 14PJ and a GHG emissions reduction of 657,022 tonnes CO2e over their operational lifetimes. The efficiency of the Subsidy Scenario in terms of program dollars spent per unit energy and GHG reduction is shown in Table 15.

Table 15: Finance + Subsidy Scenario Program Operating Cost and Efficiency

Retrofit Category	Program Operating Cost ($)	Program Operating Cost per unit Energy Reduction ($/GJ)	Program Operating Cost per unit GHG Reduction ($/tonne CO2e)
Basement/floor	$8,139,000	$7	$179
Attic	$1,194,000	$2	$45
Walls	$1,381,000	$3	$65
Draftproofing	$1,705,000	$1	$31
Space Heating (HVAC)	$3,940,000	$1	$12
Windows/Doors	$26,744,000	$6	$147
Domestic hot water	$555,000	$6	$121
Total Program	**$43,658,000**	**$3**	**$66**

Note: Dollars spent in the Finance + Subsidy Scenario are composed of subsidies and administrative costs

Scenario Efficiency Comparison

When comparing the three different EE program scenarios in Table 16, the PVs of each of their program operating costs are very similar. The Subsidy Scenario is estimated to have the lowest PV of program operating cost at $40 million, though it requires that this cost be incurred during its first and only operating year. The Finance and Finance + Subsidy Scenarios on the other hand have higher PVs of program operating costs at $43 million and $44 million respectively. Though the PVs of each EE program scenario's program operating costs are similar, the Finance and Finance + Subsidy Scenarios require much less upfront capital in the first year. Program operating costs in the first year of the Finance and Finance + Subsidy Scenarios are estimated to be around $2 million, reducing over time to around $800,000 in the final year of operation. All three EE program scenarios also induce energy savings and GHG reductions at similar levels of efficiency.

Table 16: Program Scenarios Total Cost and Efficiency Comparison

Program Scenario	Program Operating Cost ($)	Program Operating Cost per unit Energy Reduction ($/GJ)	Program Operating Cost per unit GHG Reduction ($/tonne CO2e)
Subsidy	$39,971,000	$3	$60
Finance	$42,615,000	$3	$66
Finance + Subsidy	$43,658,000	$3	$66

To assess the validity of the energy savings cost effectiveness estimates I compare them to real world examples. For ease of comparison I convert the previously mentioned US utility efficiency program cost-effectiveness data reported in Friedrich et al. (2009) to $/GJ. This results in ranges of roughly $4 to $9 per GJ of electricity savings, and $3 to $5 per GJ of natural gas savings induced by energy efficiency programs, in 2007 U.S. dollars. Using a conversion factor of 0.04987 tonne CO2e/GJ for natural gas gives a cost-effectiveness range of about $60 to $100 per tonne CO2e for US utility efficiency programs. My cost-effectiveness estimates are comparable to these US utility efficiency program cost-effectiveness values. That being said, the results of my three hypothetical EE program scenarios are at the high end of these EE program cost-effectiveness ranges. As I do not account for free riders in my estimates I may be overstating the efficiency of my hypothetical EE program scenarios. Free riders are not accounted for because it is unclear how many free riders would participate in a finance based EE program scenario vs the Subsidy Scenario. If free riders were accounted for I would expect my cost-effectiveness values to increase for all scenarios, with the greatest increase seen under the Subsidy Scenario. This is because free riders may be more likely to participate in the Subsidy Scenario than in the Finance Scenario.

Though all three EE program scenarios result in similar program operating costs and efficiencies, it is important to remember where the funding for each EE program scenario is assumed to come from. All program operating costs under the Subsidy Scenario are sourced from the administering organization, which in this case is assumed to be the provincial government. The provincial government may decide to fund the Subsidy Scenario directly with savings, or borrow the funds. The program operating costs under the Finance Scenario, and to a large extent, the Finance + Subsidy Scenario, are sourced from the EE program participants themselves, in the form of a one quarter share of the annual interest payments made on the EE measure loans. If all Finance Scenario program operating costs can be sourced from program participants, the financial burden placed on the administering organisation may be negligible, where as under the Subsidy Scenario, the administering organization will need to cover the entire program operating cost themselves.

7.2.4 Sensitivity Analysis

EE measure NPV as a Function of the Consumer Discount Rate

Here I perform a sensitivity analysis on the NPV of one EE measure, installed in housing archetype #141,[19] by adjusting the consumer discount rate used in the EE measure NPV calculation. The EE measure, selected from the draftproofing category, is air sealing with a target of +15%. Figure 1 shows the NPVs of this measure, resulting from each of the three hypothetical EE program scenarios. Data tables for this graph are in Appendix A.

In this instance, the EE measure NPV under all EE program scenarios, including when the measure is paid for in full by the household, decreases as the consumer discount rate increases. The Finance and Finance + Subsidy Scenarios result in the same NPVs. This is because no subsidies are applied during the Finance + Subsidy Scenario under these certain conditions. Initially, all three EE program scenarios result in a positive EE measure NPV, while paying the entire initial incremental capital cost of the EE measure out of pocket results in a negative NPV for the household. It is

[19] Housing archetype codes are defined in Appendix A.

interesting to note that in this case, as the consumer discount rate approaches 30% the NPV under the Subsidy Scenario becomes negative, while the NPVs under the Finance and Finance + Subsidy Scenarios remain positive. This occurs because future energy bill savings are discounted so heavily that they no longer outweigh the, after subsidy, initial capital cost of the EE measure paid by the household under the Subsidy Scenario. This capital cost does not exist for the household under the Finance Scenario, as the entire EE measure incremental capital cost is financed. Continuing to a consumer discount rate of 45% results in the further decrease of the EE measure NPV.

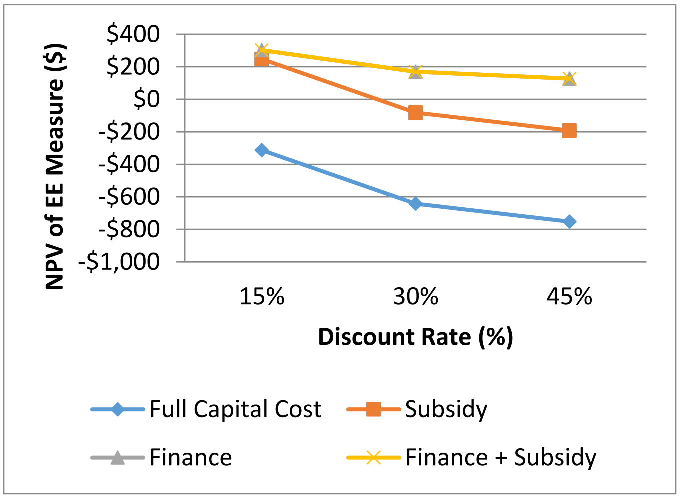

Figure 4: NPV of Draftproofing Measure (air sealing, target +15%) at Varying Consumer Discount Rates, When Installed in Archetype 141 Under Each EE Scenario.

EE Program Operating Cost as a Function of the Discount Rate

The estimated PV of the Finance, and Finance + Subsidy Scenario program operating costs are dependant on the discount rate used to calculate them. This is the discount rate applied to future cash flows by the administering organization, and is different from the high consumer discount rate placed on EE measures. The use of a higher discount rate leads to lower estimated finance based program operating costs, and visa versa. This is shown in Figure 5. Initially the PV of the Finance, and Finance + Subsidy Scenario program operating costs are greater than that of the Subsidy Scenario. But as the discount rate approaches 4% the PV of the Finance, and Finance + Subsidy Scenario program operating costs drop below those of the Subsidy Scenario. This is because no discounting is applied to the Subsidy Scenario program operating cost as all costs are incurred by this scenario in the initial year of operation.

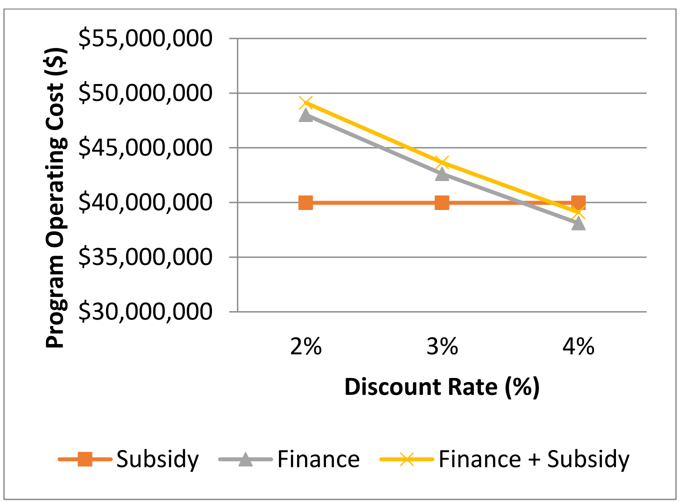

Figure 5: Present Value of EE Scenario Program Operating Cost, at Varying Discount Rates

8. Conclusion

In this study, I have sought to answer the research question of whether or not a hypothetical province wide, whole home, innovative EE financing program could be operated more cost-effectively than a comparable EE subsidy program, in terms of dollars spent per unit energy saved, and GHG emissions reduction. Based on data from the 2011/12 LiveSmart BC 3.0, and ecoENERGY EE incentive programs, I have pursued my research question by estimating the outcomes of three hypothetical EE program models in terms of their total program operating cost, and efficiency with which they deliver energy and GHG savings. These three models are referred to as the Subsidy Scenario, Finance Scenario, and Finance + Subsidy Scenario. The Finance and Finance + Subsidy Scenarios build off of the Subsidy Scenario, and are designed to approximate the EE measure uptake and cost of a long term, low interest loan program similar to on-property tax bill and on-utility bill financing.

Household Perspective

From the household's perspective, across all three program scenarios the type of energy used for space heating in a home has a large effect on the NPV of individual EE measures. This is due to the relative costs of electricity and natural gas. Since at least 2011, electricity rates in BC have been about twice as expensive as natural gas rates in terms of $/GJ. I have estimated that by 2041 this price gap may increase to a point where electricity rates become three times greater than natural gas rates. Thus, the dollar value of a household's reduction in electricity use is much greater than the dollar value attained from the equivalent energy reduction in natural gas use. Therefore, households with an electric heat source will likely see a greater reduction in their energy bills due to EE measure induced energy savings. This can be seen in Table 8 to Table 11, where electrically heated homes are shown to have a greater percent of EE measures with positive NPVs, and higher average NPVs by EE measure category than do homes heated with natural gas. The high cost of electricity may also act to discourage households from switching from natural gas HVAC systems to electrical systems such as air and ground source heat pumps.

The sensitivity analysis shows that the choice of consumer discount rate applied to an EE measure can have a differing effect on the EE measure's NPV, depending on which EE program scenario is in place. With an increase in the consumer discount rate, the EE measure NPV resulting from the Subsidy Scenario decreases at a greater rate than the EE measure NPV resulting from the Finance, and Finance + Subsidy Scenarios. Because of this, certain EE measure/archetype combinations can result in a positive NPV under the Finance Scenario, and a negative NPV under the Subsidy Scenario. If a household's decision to invest in an EE measure is based on an EE measure's NPV, then knowing what discount rate a household will apply to EE measures may aid in the design of effective EE programs.

In this paper, I focused on the subsidisation and financing of individual EE measures, and have contributed to prior research on EE measure NPVs. EE measures such as attic and wall insulation, draftproofing, and HVAC systems were found to have dominantly positive NPVs and others such as basement/floor insulation, windows/doors, and domestic hot water heaters were found to have dominantly negative NPVs. Even though an EE measure may have a negative NPV, it can still induce important energy savings. To encourage the uptake of EE measures with a negative NPV, and create deeper EE retrofits it may be possible to bundle EE measures having negative NPVs, with EE measures having highly positive NPVs. This could result in the bundled EE measures having an overall positive NPV. This may be important for encouraging households to undertake deeper EE retrofits of their homes, and produce greater reductions of energy consumption and GHG emissions.

Administrator Perspective

From the program administrator's perspective, I contribute to prior research on energy efficiency policy, and program evaluation, by calculating and comparing the PV of total program operating costs, and efficiencies, of three hypothetical EE program scenarios. I find that the PVs of each EE program scenario's total program operating costs are very similar, with the Subsidy Scenario having the lowest estimated PV total program operating cost. The Subsidy Scenario also results in the most efficient use of program dollars spent per GHG emissions reduction at $60/tonne CO2e, while each EE program scenario has the same efficiency in terms of program dollars spent per unit of energy saved at $3/GJ. These estimates are comparable to cost-effectiveness values reported from various US utility efficiency programs studied by Friedrich et al. (2009). As can be seen in the sensitivity analysis, changing the discount rate used by the administering organization to value future operating cost cash flows can lead to the PV total program operating cost of the Finance, and Finance + Subsidy Scenarios becoming even great than, or less than, the Subsidy Scenario operating cost. Changing this discount rate also effects the perceived efficiency of the finance based scenarios as the PV operating cost changes while energy savings and GHG emission reductions remain constant.

My research shows that even though all three hypothetical EE program scenarios result in similar PV program operating costs, their direct costs to the program administrator differ. Under the Subsidy Scenario, all operating costs are sourced from the program administrator. But under the Finance Scenario, funding for operating costs is sourced from the interest payments made by borrowers participating in the program. Because of this, the Finance Scenario can be provided at, or close to, no direct cost to the administering organization. As it is estimated that both Subsidy and Finance Scenarios will induce similar levels of energy savings and GHG emission reductions, the Finance Scenario is the most cost-effective of the three EE program scenarios from the perspective of the administering organization.

From the literature, it can be argued that innovative EE financing programs, such as on-property tax bill and on-utility bill financing, may reduce economic barriers to investment in residential EE measures such as: high initial capital cost, limited financing, long payback time, and the principle-agent problem. By addressing these EE barriers, innovative EE financing programs may experience greater participation from households with lower incomes or poor credit, those that are concerned about making a long term investment in a home they may move away from soon, and those that rent. At the same time, these financing programs may work to discourage the participation of free riders, and allow for a more targeted and effective use of program spending. The models I developed in this paper are based on historical participation levels in the 2011/12 LiveSmart BC 3.0, and ecoENERGY EE incentive programs, and they are unable to account for the effects that an EE financing program may have on uptake from these specific segments of the population. The effect that the availability of an EE financing program may have on these population groups represents an interesting area for further research.

9. Bibliography

Allouhi, A., El Fouih, Y., Kousksou, T., Jamil, A., Zeraouli, Y., & Mourad, Y. (2015). Energy consumption and efficiency in buildings: current status and future trends. *Journal of Cleaner Production*, *109*, 118–130. http://doi.org/10.1016/j.jclepro.2015.05.139

Arimura, T. H., Li, S., Newell, R. G., & Palmer, K. (2012). *Cost-effectiveness of electricity energy efficiency programs*. *Energy Journal* (Vol. 33). http://doi.org/10.5547/01956574.33.2.4

Bank of Canada. (2017). Bank of Canada Prime Interest Rates 2011-2012. Retrieved March 16, 2017, from http://www.bankofcanada.ca/rates/interest-rates/canadian-interest-rates/

Bardhan, A., Jaffee, D., Kroll, C., & Wallace, N. (2014). Energy efficiency retrofits for U.S. housing: Removing the bottlenecks. *Regional Science and Urban Economics*, *47*, 45–60. http://doi.org/10.1016/j.regsciurbeco.2013.09.001

BC Hydro. (2013). *Evaluation of the LiveSmart BC Efficiency Incentive Program F2009 - F2011*. Vancouver, BC.

BC Hydro. (2015). *2015 Rate Design Application, Appendix C-3F 2014 Residential End Use Survey*. Vancouver, BC.

BC Hydro. (2016). *BC Hydro Greenhouse Gas Intensities*. Vancouver, BC. Retrieved from https://www.bchydro.com/content/dam/BCHydro/customer-portal/documents/corporate/environment-sustainability/environmental-reports/ghg-intensities-2007-2015.pdf

BC Hydro. (2017a). BC Hydro Facilities. Retrieved March 21, 2017, from https://www.bchydro.com/energy-in-bc/our_system/generation/our_facilities.html

BC Hydro. (2017b). *British Columbia Hydro and Power Authority: Electric Tariff, Rate Schedule 1101*. Retrieved from https://www.bchydro.com/content/dam/BCHydro/customer-portal/documents/corporate/tariff-filings/electric-tariff/bchydro-electric-tariff.pdf

BC Ministry of Energy and Mines Energy Efficiency Branch. (2015). *A Review of Whole Home Energy Retrofit Programs in British Columbia from 2007-2015*.

BC Ministry of Environment. (2016a). *2016/17 B.C. BEST PRACTICES METHODOLOGY FOR QUANTIFYING GREENHOUSE GAS EMISSIONS*. Victoria, BC. Retrieved from http://www2.gov.bc.ca/assets/gov/environment/climate-change/cng/methodology/2016-17-pso-methodology.pdf

BC Ministry of Environment. (2016b). British Columbia Greenhouse Gas Inventory - Key data and targets 2014. Retrieved November 2, 2016, from http://www2.gov.bc.ca/gov/content/environment/climate-change/data/provinical-inventory

Bierth, C., Peyman, H., & Svedova, J. (2010). *Addressing barriers to energy efficiency in Vancouver*. Vancouver, BC. Retrieved from http://www.sauder.ubc.ca/Faculty/Research_Centres/ISIS/Resources/~/media/A6AD2F658A8944CE9165C0622133E564.ashx

Canadian Bankers Association. (2016). Number of Residential Mortgages in Arrears. Retrieved October 12, 2016, from http://www.cba.ca/mortgages-in-arrears

Charlier, D. (2015). Energy efficiency investments in the context of split incentives among French households. *Energy Policy*, *87*, 465–479. http://doi.org/10.1016/j.enpol.2015.09.005

City of Nelson. (2016). EcoSave On Bill Financing. Retrieved October 4, 2016, from http://www.nelson.ca/EN/main/services/electrical-services/energy-grants/on-bill-financing-q-a.html

de la Rue du Can, S., Leventis, G., Phadke, A., & Gopal, A. (2014). Design of incentive programs for accelerating penetration of energy-efficient appliances. *Energy Policy*, *72*, 56–66. http://doi.org/10.1016/j.enpol.2014.04.035

de la Rue du Can, S., Shah, N., & Phadke, A. A. (2011). *Country Review of Energy-Efficiency Financial Incentives in the Residential Sector*. Berkeley, CA. Retrieved from https://eta.lbl.gov/sites/all/files/publications/lbnl-5033e.pdf

FortisBC. (2016). *Natural Gas Demand-Side Management Programs 2015 Annual Report*. Surrey, BC. Retrieved from https://www.fortisbc.com/About/RegulatoryAffairs/GasUtility/NatGasBCUCSubmissions/Documents/160330_FEI_2015_DSM_Annual_Report_FF.PDF

Frappé-Sénéclauze, T.-P., & Heerema, D. (2016). *Deep emissions reduction in the existing building stock - sketch of a retrofit strategy for B.C. [Power Point Slides]*. Vancouver, BC. Retrieved from https://drive.google.com/drive/folders/0B_C2JmpcBJsldzVmQ1FmQ21IYU0

Friedrich, K., Eldridge, M., York, D., Witte, P., & Kushler, M. (2009). *Saving Energy Cost Effectively: A National Review of the Cost of Ennergy Saved Through Utility-Sector Energy Efficiency Programs*. Retrieved from https://library.cee1.org/sites/default/files/library/8570/CEE_Eval_Saving Energy Cost_Effectively_Sep2009.pdf

Gillingham, K., Newell, R. G., & Palmer, K. (2004). Retrospective Examination of Demand-Side Efficiency Policies. *RFF Working Paper*, (June), 1–100. http://doi.org/10.1146/annurev.energy.31.020105.100157

Gillingham, K., Newell, R. G., & Palmer, K. (2009). *Energy Efficiency Economics and Policy*. *National Bureau of Economic Research Working Paper Series* (Vol. No. 15031). http://doi.org/10.3386/w15031

Gillingham, K., Newell, R., & Palmer, K. (2006). Energy Efficiency Policies: A Retrospective

Examination. *Annual Review of Environment and Resources*, *31*(1), 161–192. http://doi.org/10.1146/annurev.energy.31.020105.100157

GLJ Petroleum Consultants. (2017). GLJ Petroleum Consultants, Historical Forecasts. Retrieved February 23, 2017, from https://www.gljpc.com/historical-forecasts

Golove, W. H., & Eto, J. H. (1996). *Market Barriers to Energy Efficiency: A Critical Reappraisal of the Rationale for Public Policies to Promote Energy Efficiency*. Berkeley, CA. Retrieved from https://emp.lbl.gov/publications/market-barriers-energy-efficiency

Goodward, J. (2011). *Public-private finance tools for energy efficiency*. *World Resources Institute*. Retrieved from http://www.wri.org/publication/bottom-line-public-private-finance-tools-energy-efficiency

Halifax Regional Council. (2015). *Solar City Pilot Program Summary Council Report*. Retrieved from http://www.halifax.ca/council/agendasc/documents/150331ca1117.pdf

Hausman, J. A. (1979). Individual Discount Rates and the Purchase and Utilization of Energy-Using Durables. *The Bell Journal of Economics*, *10*(1), 33–54. http://doi.org/10.2307/3003318

HERO. (2016). How the HERO Program and PACE Financing Work. Retrieved September 3, 2016, from https://heroprogram.com/how-it-works

Houston, D. a. (1983). Implicit Discount Rates and the Purchase of Untried, Energy-Saving Durable Goods. *Journal of Consumer Research*, *10*(2), 236–246. http://doi.org/10.1086/208962

IPCC. (2007). *Climate Change 2007: Mitigation. Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*. *Intergovernmental Panel on Climate Change*. Cambridge, United Kingdom and New York, NY, USA: Cambridge University Press. Retrieved from https://www.ipcc.ch/publications_and_data/publications_ipcc_fourth_assessment_report_wg3_report_mitigation_of_climate_change.htm

Jaffe, A. B., Newell, R. G., & Stavins, R. N. (2004). Economics of Energy Efficiency. *Encyclopedia of Energy*, *2*, 79–90. Retrieved from http://scholar.harvard.edu/files/stavins/files/encyclopedia_of_energy_2004.pdf

Jollands, N., Waide, P., Ellis, M., Onoda, T., Laustsen, J., Tanaka, K., … Meier, A. (2010). The 25 IEA energy efficiency policy recommendations to the G8 Gleneagles Plan of Action. *Energy Policy*, *38*(11), 6409–6418. http://doi.org/10.1016/j.enpol.2009.11.090

Kaza, N., Quercia, R. G., & Tian, C. Y. (2014). Home Energy Efficiency and Mortgage Risks. *Cityscape*, *16*(1), 279–298. Retrieved from http://ssrn.com/abstract=2416949

Letschert, V. E., Bojda, N., Ke, J., & McNeil, M. A. (2012). *Estimate of Cost-Effective Potential for Minimum Efficiency Performance Standards in 13 Major World Economies Energy*

Savings, Environmental and Financial Impacts. Berkeley, CA. Retrieved from https://ies.lbl.gov/sites/all/files/lbnl-5723e_pdf.pdf

McNeil, M. A., Letschert, V. E., & de la Rue du Can, S. (2008). *Global Potential of Energy Efficiency Standards and Labeling Programs*. *Lawrence Berkeley National Laboratory*. Retrieved from https://eaei.lbl.gov/sites/all/files/lbnl-760e.pdf

Morgan, S., Lothian, N., & Thibault, B. (2015). *Loans for Heat: Towards a Yellowknife Energy Savings Program*. Yellowknife, NT. Retrieved from https://www.yellowknife.ca/en/resources/Green_Energy_Retrofit_Program_-_March_31_2015_-_Pembina.PDF

Murphy, L., & Meijer, F. (2011). Waking a sleeping giant: Policy tools to improve the energy performance of the existing housing stock in the Netherlands. In *ECEEE 2011 Summer Study: Energy efficiency first: the foundation of a low carbon society, Belambra Presqu'île de Giens, France, 6-11 June, 2011* (pp. 1107–1118). ECEEE. Retrieved from https://repository.tudelft.nl/islandora/object/uuid:c1f0c794-f094-4d4d-a2ed-29aa53e62718?collection=research

Natural Resources Canada. (2014). Comprehensive Energy Use Database, Residential Sector - British Columbia. Retrieved October 18, 2016, from http://oee.nrcan.gc.ca/corporate/statistics/neud/dpa/menus/trends/comprehensive/trends_res_bc.cfm

PACENation. (2016). Residential PACE Near You. Retrieved September 21, 2016, from http://pacenation.us/pace-programs/residential/

Pal, L. A. (2009). *Beyond Policy Analysis: Public Issue Management in Turbulent Times* (4th ed.). Toronto: Nelson Education.

Patton, M. Q. (2008). *Utilization-Focused Evaluation* (4th ed.). Sage publications.

Persram, S. (2011). *Property Assessed Payments for Energy Retrofits*. Retrieved from http://www.davidsuzuki.org/publications/downloads/2011/Property-Assessed-Payments-for-Energy-Retrofits-recommendations-1.pdf

Poirier, M., Dunsky, P., & Berg, K. (2012). *An Analytical Foundation in Support of MEM's On-Bill Financing Program for British Columbia*.

Residential Tenancy Branch. (2017). BC Residential Tenancy Act [SBC 2002] Chapter 78. Retrieved March 14, 2017, from http://www.housing.gov.bc.ca/rtb/bc_laws/RTA.html#part3

Sanstad, A., Hanemann, M., & Auffhammer, M. (2006). *End-use Energy Efficiency in a "Post-Carbon" California Economy: Policy Issues and Research Frontiers*. Berkeley, CA: The California Climate Change Center at UC-Berkeley. Retrieved from http://eec1.ucdavis.edu/education/EEC-classes/eeclimate/class-readings/sanstad%5Cnchap%5Cn6.pdf

Sathaye, J., & Murtishaw, S. (2004). *Market Failures, Consumer Preferences, and Transaction Costs in Energy Efficiency*. Berkeley, CA. Retrieved from http://escholarship.org/uc/item/6718v9dw

State and Local Energy Efficiency Action Network. (2014). *Energy Efficiency Financing Program Implementation Primer. Prepared by M. Zimring, Lawrence Berkeley National Laboratory*. Retrieved from https://www4.eere.energy.gov/seeaction/system/files/documents/financing_primer_0.pdf

Statistics Canada. (2011a). Family Definition. Retrieved April 18, 2017, from http://www.statcan.gc.ca/pub/75f0011x/2011001/notes/fam-eng.htm#tableb

Statistics Canada. (2011b). Statistics Canada, 2011 National Household Survey, Statistics Canada Catalogue no. 99-014-X2011026. Retrieved April 18, 2017, from http://www12.statcan.gc.ca/nhs-enm/2011/dp-pd/dt-td/Ap-eng.cfm?LANG=E&APATH=3&DETAIL=0&DIM=0&FL=A&FREE=0&GC=0&GID=0&GK=0&GRP=0&PID=106699&PRID=0&PTYPE=105277&S=0&SHOWALL=0&SUB=0&Temporal=2013&THEME=98&VID=0&VNAMEE=&VNAMEF=

Statistics Canada. (2012). Statistics Canada. Table 206-0004 - Canadian Income Survey (CIS). Retrieved April 18, 2017, from http://www5.statcan.gc.ca/cansim/a26?lang=eng&retrLang=eng&id=2060004&&pattern=&stByVal=1&p1=1&p2=-1&tabMode=dataTable&csid=

Statistics Canada. (2013). Household size, by province and territory, 2011 Census of Population and Statistics Canada catalogue no. 98-313-XCB. Retrieved October 12, 2016, from http://www.statcan.gc.ca/tables-tableaux/sum-som/l01/cst01/famil53c-eng.htm

Statistics Canada. (2016a). Dwelling Definition. Retrieved October 10, 2016, from http://www.statcan.gc.ca/eng/concepts/definitions/privdwel

Statistics Canada. (2016b). Household Definition. Retrieved October 10, 2016, from http://www23.statcan.gc.ca/imdb/p3Var.pl?Function=Unit&Id=96113

Statistics Canada. (2016c). *Report on Energy Supply and Demand in Canada – 2014 Preliminary (57-003-X)*. Retrieved from http://www5.statcan.gc.ca/olc-cel/olc.action?ObjId=57-003-X&ObjType=2&lang=en&Limit=1

Statistics Canada. (2016d). *Statistics Canada. Table 153-0161 - Household energy consumption, British Columbia, 2011-2013*. Retrieved from http://www.statcan.gc.ca/daily-quotidien/160318/dq160318d-cansim-eng.htm

Statistics Canada. (2016e). Table 203-0027: Survey of household spending (SHS), dwelling characteristics and household equipment at time of interview, Canada, regions and provinces, annual (number unless otherwise noted), CANSIM (database). Retrieved October 8, 2016, from http://www5.statcan.gc.ca/cansim/a26?lang=eng&id=2030027%0A

Supple, D., & Nix, O. (2010). *Unlocking the Building Retrofit Market: Commercial PACE* *financing*. Retrieved from http://www.buildingefficiencyinitiative.org/sites/default/files/legacy/InstituteBE/media/Library/Resources/Financing-Clean-Energy/Issue-Brief-Unlocking-the-Building-Retrofit-Market-PACE-Financing.pdf

Sutherland, R. J. (1991). Market Barriers to Energy-Efficiency Investments. *The Energy Journal*, *12*(3), 15–34. Retrieved from http://www.jstor.org/stable/41322426

Train, K. E. (1994). Estimation of net savings from energy-conservation programs. *Energy*, *19*(4), 423–441. http://doi.org/10.1016/0360-5442(94)90121-X

U.S. Department of Energy. (2016). *Best Practice Guidelines for Residential PACE Financing Programs*. Washington, DC. Retrieved from https://energy.gov/sites/prod/files/2016/11/f34/best-practice-guidelines-RPACE.pdf

Walls, M., Gerarden, T., Palmer, K., & Bak, X. F. (2017). Is energy efficiency capitalized into home prices? Evidence from three U.S. cities. *Journal of Environmental Economics and Management*, *82*, 104–124. http://doi.org/10.1016/j.jeem.2016.11.006

Zimring, M., Leventis, G., Borgeson, M., Thompson, P., Hoffman, I., & Goldman, C. (2014). *Financing Energy Improvements on Utility Bills: Technical Appendix — Case Studies*. Retrieved from https://www4.eere.energy.gov/seeaction/system/files/documents/publications/chapters/onbill_financing_appendix.pdf

10. Appendix A: Data Tables

Table 17: Housing Archetypes and Number of Homes per Archetype

Archetype Code	Climate zone	Construction Date	Number of Storeys	HVAC	Number of Homes per Archetype
111	South Coastal (Vancouver)	Pre-1976	1	Natural Gas	3002
121	South Coastal (Vancouver)	Pre-1976	2	Natural Gas	2295
131	South Coastal (Vancouver)	Post-1976	1	Natural Gas	1235
141	South Coastal (Vancouver)	Post-1976	2	Natural Gas	3876
112	South Coastal (Vancouver)	Pre-1976	1	Electricity	809
122	South Coastal (Vancouver)	Pre-1976	2	Electricity	398
132	South Coastal (Vancouver)	Post-1976	1	Electricity	1108
142	South Coastal (Vancouver)	Post-1976	2	Electricity	981
211	Southern Interior (Summerland)	Pre-1976	1	Natural Gas	1199
221	Southern Interior (Summerland)	Pre-1976	2	Natural Gas	235
231	Southern Interior (Summerland)	Post-1976	1	Natural Gas	952
241	Southern Interior (Summerland)	Post-1976	2	Natural Gas	474
212	Southern Interior (Summerland)	Pre-1976	1	Electricity	303
222	Southern Interior (Summerland)	Pre-1976	2	Electricity	47
232	Southern Interior (Summerland)	Post-1976	1	Electricity	205
242	Southern Interior (Summerland)	Post-1976	2	Electricity	117
351	Northern (Prince George)	All	1	Natural Gas	640
352	Northern (Prince George)	All	1	Electricity	46
451	Northern (Fort St-John)	All	1	Natural Gas	64
452	Northern (Fort St-John)	All	1	Electricity	0
				Total:	17986

Note: Adopted from Poirier et al. (2012)

Table 18: Individual EE measure Subsidies

Individual EE Measures	LiveSmartBC 3.0 Subsidies		ecoENERGY Subsidies
	Interior/North	S.Coastal	
Air sealing, target +25%	$500	$400	$430
Air sealing, target +15%	$300	$250	$310
Air sealing, target +5%	$125	$100	$190
Air sealing with HVI certified HRV installed	$1,500	$1,200	$805
Attic insulation, upgrade from R12 or less to R50	$750	$600	$750
Attic insulation, upgrade from R13-25 to R50	$375	$300	$375
Attic insulation, upgrade from R26-35 to R50	$125	$100	$125
Wall insulation, add at least R9 to achieve a minimum of R12	$1,500	$1,200	$1,875
Wall insulation, add at least R3.8 to achieve a minimum of R12	$1,000	$750	$1,125
Wall insulation, upgrade uninsulated main walls by adding at least R9	$1,500	$1,200	$1,875
Wall insulation, upgrade uninsulated main walls by adding at least R3.8	$1,000	$750	$1,125
Wall insulation, upgrade uninsulated main walls to R12	$1,500	$1,200	$1,875
Basement wall insulation, add at least R23	$1,250	$1,000	$1,250
Basement wall insulation, add at least R10	$625	$500	$625
Basement header, add R20	$125	$100	$125
Exposed floor, add at least R20	$225	$175	$190
Replace all windows with Energy Star windows rated for one climate zone colder	$70	$60	$40
Replace all doors with Energy Star doors rated for one climate zone colder	$70	$60	$40
Replace all windows with Energy Star windows rated for same climate zone	$35	$30	$40
Replace all doors with Energy Star doors rated for same climate zone	$35	$30	$40
Energy Star gas furnace 95% AFUE with DC variable speed motor	$600	$500	$790
Energy Star condensing gas boiler 90% AFUE	$600	$500	$750
Install Energy Star rated ASHP (heating and cooling)	$1,000	$1,000	$500
Install Energy Star rated GSHP (heating and cooling)	$2,500	$2,500	$4,375
Electronic thermostats (replace at least 5)	$50	$50	$40
Domestic hot water - Energy Star rated condensing (tankless) with EF of at least 0.90	$300	$300	$375
Domestic hot water - Energy Star rated tankless unit with EF of at least 0.82	$200	$200	$315
Domestic hot water - condensing gas storage type with thermal efficiency of 94%	$300	$300	$375
Domestic hot water - condensing gas storage type with thermal efficiency of 90%	$200	$200	$0
Electric heat pump water heater - integrated	$500	$500	$0
Electric heat pump water heater - add-on	$250	$250	$0
Solar water heater	$500	$500	$1,250
Drainwater heat recovery	$150	$150	$165

Note: Adapted from Poirier et al. (2012) and BC Ministry of Energy and Mines Energy Efficiency Branch (2015)

Table 19: Dollar Amount Spent Per Measure Category by Scenario (Before Tax)

			Subsidy Scenario			Finance Scenario				Finance + Subsidy Scenario			
Retrofit Category	**# of Individual Measures Installed**	**Total Capital Cost (x1000)**	**Applied Subsidies (x1000)**	**Admin Cost (x1000)**	**Capital Cost Paid by Consumers (x1000)**	**Applied Subsidies (x1000)**	**Admin Cost (x1000)**	**Financed Amount (x1000)**	**Capital Cost Paid by Consumers (x1000)**	**Applied Subsidies (x1000)**	**Admin Cost (x1000)**	**Financed Amount (x1000)**	**Capital Cost Paid by Consumers (x1000)**
Basement/floor	4,628	$28,392	$4,928	$1,031	$23,464	$0	$8,139	$28,392	$0	$0	$8,139	$28,392	$0
Attic	4,553	$4,125	$2,933	$613	$1,193	$0	$1,158	$4,040	$0	$13	$1,182	$4,113	$0
Walls	1,844	$3,361	$4,711	$985	-$1,350	$0	$405	$1,415	$0	$453	$928	$2,909	$0
Draftproofing	7,029	$5,895	$3,433	$718	$2,462	$0	$1,674	$5,840	$0	$16	$1,689	$5,879	$0
Space Heating (HVAC)	12,753	$14,231	$15,916	$3,329	-$1,685	$0	$3,940	$14,231	$0	$0	$3,940	$14,231	$0
Windows/Doors	8,088	$93,296	$701	$147	$92,595	$0	$26,744	$93,296	$0	$0	$26,744	$93,296	$0
Domestic hot water	817	$2,029	$434	$91	$1,595	$0	$555	$2,029	$0	$0	$555	$2,029	$0
Totals	39,713	$151,330	$33,056	$6,915	$118,274	$0	$42,615	$149,243	$0	$482	$43,176	$150,848	$0

Table 20: Net Present Values of a Draftproofing Upgrade by Housing Archetype and EE Scenario with a Discount Rate of 15%

		Housing Archetype Characteristics				Scenario Net Present Value (discount rate: 15%)			
EE Measure Description	**Archetype Code**	**Climate zone**	**Construction Date**	**Storeys**	**HVAC system**	**Full Capital Cost**	**Incentives**	**Finance**	**Finance + Subsidy**
Draftproofing:	111	South Coastal (Vancouver)	Pre-1976	1	Natural Gas	-$577	-$17	-$130	-$130
Air sealing,	121	South Coastal (Vancouver)	Pre-1976	2	Natural Gas	$16	$576	$567	$567
target +15%	131	South Coastal (Vancouver)	Post-1976	1	Natural Gas	-$669	-$109	-$213	-$213
	141	South Coastal (Vancouver)	Post-1976	2	Natural Gas	-$313	$247	$302	$302
	211	Southern Interior (Summerland)	Pre-1976	1	Natural Gas	-$494	$116	-$48	$0
	221	Southern Interior (Summerland)	Pre-1976	2	Natural Gas	$442	$1,052	$993	$993
	231	Southern Interior (Summerland)	Post-1976	1	Natural Gas	-$624	-$14	-$168	-$168
	241	Southern Interior (Summerland)	Post-1976	2	Natural Gas	$13	$623	$628	$628
	351	Northern (Prince George)	All	1	Natural Gas	-$484	$126	$16	$16
	451	Northern (Fort St-John)	All	1	Natural Gas	-$347	$263	$153	$153

Table 21: Net Present Values of a Draftproofing Upgrade by Housing Archetype and EE Scenario with a Discount Rate of 30%

		Housing Archetype Characteristics				Scenario Net Present Value (discount rate: 30%)			
EE Measure Description	**Archetype Code**	**Climate zone**	**Construction Date**	**Storeys**	**HVAC system**	**Full Capital Cost**	**Incentives**	**Finance**	**Finance + Subsidy**
Draftproofing:	111	South Coastal (Vancouver)	Pre-1976	1	Natural Gas	-$665	-$105	-$76	-$76
Air sealing,	121	South Coastal (Vancouver)	Pre-1976	2	Natural Gas	-$407	$153	$320	$320
target +15%	131	South Coastal (Vancouver)	Post-1976	1	Natural Gas	-$725	-$165	-$123	-$123
	141	South Coastal (Vancouver)	Post-1976	2	Natural Gas	-$642	-$82	$169	$169
	211	Southern Interior (Summerland)	Pre-1976	1	Natural Gas	-$618	-$8	-$29	-$29
	221	Southern Interior (Summerland)	Pre-1976	2	Natural Gas	-$165	$445	$562	$562
	231	Southern Interior (Summerland)	Post-1976	1	Natural Gas	-$699	-$89	-$97	-$97
	241	Southern Interior (Summerland)	Post-1976	2	Natural Gas	-$457	$153	$354	$354
	351	Northern (Prince George)	All	1	Natural Gas	-$654	-$44	$7	$7
	451	Northern (Fort St-John)	All	1	Natural Gas	-$576	$34	$85	$85

Table 22: Net Present Values of a Draftproofing Upgrade by Housing Archetype and EE Scenario with a Discount Rate of 45%

		Housing Archetype Characteristics				Scenario Net Present Value (discount rate: 45%)			
EE Measure Description	**Archetype Code**	**Climate zone**	**Construction Date**	**Storeys**	**HVAC system**	**Full Capital Cost**	**Incentives**	**Finance**	**Finance + Subsidy**
Draftproofing:	111	South Coastal (Vancouver)	Pre-1976	1	Natural Gas	-$694	-$134	-$56	-$56
Air sealing,	121	South Coastal (Vancouver)	Pre-1976	2	Natural Gas	-$548	$12	$240	$240
target +15%	131	South Coastal (Vancouver)	Post-1976	1	Natural Gas	-$744	-$184	-$91	-$91
	141	South Coastal (Vancouver)	Post-1976	2	Natural Gas	-$752	-$192	$127	$127
	211	Southern Interior (Summerland)	Pre-1976	1	Natural Gas	-$659	-$49	-$21	-$21
	221	Southern Interior (Summerland)	Pre-1976	2	Natural Gas	-$368	$242	$420	$420
	231	Southern Interior (Summerland)	Post-1976	1	Natural Gas	-$724	-$114	-$72	-$72
	241	Southern Interior (Summerland)	Post-1976	2	Natural Gas	-$614	-$4	$265	$265
	351	Northern (Prince George)	All	1	Natural Gas	-$710	-$100	$6	$6
	451	Northern (Fort St-John)	All	1	Natural Gas	-$652	-$42	$64	$64