JÖNKÖPING INTERNATIONAL BUSINESS SCHOOL
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Energy Conservation in the Canadian Residential Sector

Revealing Potential Carbon Emission Reductions through Cost Effectiveness Analysis

Bachelor's Thesis in Economics

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Alvaro Ruiz-Gomez

Jönköping, January 2011

Tag Cloud

This is a tag cloud of the 50 most common words in the thesis.

The higher the frequency of use, the bigger the word.

“Information changes behavior”

John Sviokla 2008

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Abstract

The study uses Cost Effectiveness Analysis (CEA) as a method to analyse the economic and environmental impact of carbon dioxide (CO_2e) emission abatement projects in the Canadian residential sector. It includes the more traditional environmental and economic criteria, yet it incorporates a behavioural component to the analysis. A detailed account of the environmental specifications, emission reductions, and economic considerations of 11 abatement projects are used as input for the CEA. In addition, behavioural variables, such as disposable income, home ownership, and home repair skills, are taken into account to complement the study.

The results indicate that the implementation of several of these carbon abatement projects, such as insulating hot water pipes, replacing incandescent light bulbs, installing a programmable thermostat, etc. can bring about large emission reductions together with a net economic benefit, and in most cases, without altering the levels of comfort. This method can serve as a template for the evaluation of other related projects within the climate change mitigation context in Canada and in other countries, in an attempt to increase adoption rates of such projects.

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List of Abbreviations

B/C Benefit/Cost Ratio

CBA Cost Benefit Analysis

CDA Conditional Demand Analysis

CEA Cost Effectiveness Analysis

CFL Compact Fluorescent Light

CO_2e *Carbon Dioxide Equivalent*

EM Engineering Method

GHG Green House Gas

IEA International Energy Agency

IRR Internal Rate of Return

Mt Megaton

NEB National Energy Board

NN Neural Network method

NPV Net Present Value

NPVE Net Present Value of Emissions Reduction

NRC National Resources Canada

OECD Economic Co-operation and Development

O&M Operating and Maintenance

PJ Petajoules

SEA Swedish Energy Board

UNFCCC United Nations Framework Convention on Climate

1. INTRODUCTION

Research Context

Research Problems

Justification

Purpose

Research Questions

Thesis Outline

Introduction starts with the research context, as a section designed to give the reader an overall view of three main issues: consumption and growth, environmental damage, and awareness and action. It continues with presenting the three research problems identified. After, the justification of the thesis follows. Next, the purpose is discusses and the research questions are presented. The chapter closes with the thesis outline.

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1 Introduction

1.1 Research Context

Technological advancements made possible by our ability to access energy resources have, on one hand, positively affected our lives in ways unimaginable before the industrial revolution. Longer life expectancy levels, real-time communication across the globe, and the digital revolution are just a few examples of these accomplishments. For instance, the ability to heat and cool is one important accomplishment of modern technology. Ovens, freezers, and even entire households in most industrial countries can be kept at any temperature we choose, a luxury that was not possible one hundred years ago. However, keeping our homes comfortable uses a lot of energy, most of it coming from non-renewable sources (CEA 2011). On top of this, much of this energy is gone to waste in the form of inefficiencies and excessive pollution. So, on the other hand, these technological advancements have created systematic environmental deterioration which leads to deeper worries for the environment and our society.

Consumption and Growth

Consumption, in its basic meaning, is necessary for all of nature to evolve and continue. In my view, the problem for our society lies in excessive consumption or consumption that is not sustainable. One way in which consumption is not sustainable is when using resources that are mostly non-renewable to derive utility. According to Thom Hartmann (cited in The 11th Hour 2007, min.45) oil or "ancient sunlight" as he calls it, is the fuel of our economies. Almost everything around us is either produced or indirectly derived from oil, thus making this non-renewable fuel the backbone of our world. It is estimated that for each calorie we consume a hundred oil calories were used to produce it (The Age of Stupid 2009, min.18).

Although this type of consumption may make sense from an economic perspective due to the financial gains involved, from other points of view such as that of the economist Herman Daly (cited in The 11th Hour 2007) this vision is set for failure. He contends that unsustainable consumption goes against the "parent" system which is the environment. He remarks that the economy should be seen as a subsystem of the biosphere and not the other way around. Thus, as the biosphere system is limited in resources, so should the economic system be. Daly's theory implies that human consumption patterns should behave in a sustainable manner within the limits of our ecosystem.

Despite this, the statistics show otherwise. The global economy has doubled in the past 25 years, while 60% of the world's ecosystems have been degraded (Jackson 2009). As a further strain, the world's population grew from 3 billion to almost 7 billion in the last 50 years (National Geographic 2011). "An American, Australian, and Canadian eat and consume twice as much energy as a European, 9 times more than a Chinese person, 15 times more than an Indian, and 50 times more than someone from Kenya… if everyone would consume as an American, Australian and Canadian, we would need another 4 planets" to sustain our present energy consumption habits (The Age of Stupid 2009, min.49).

Environmental Damage

"*Shrinking forests, expanding deserts, falling water tables, eroding soils, disappearing species, rising temperatures, ice melting, more destructing storms, rising sea levels; there are a long list of physical signs of environmental stress*" (Brown, cited in Planeten 2006, min.2). All of these signs are part of the global warming debate, where the consensus is that many of these problems are caused, at least in part, by human activity. Despite this common agreement among scientists regarding the contribution of the human footprint to the imbalance of the ecosystem, outside the scientific community there are still some who are skeptical. For example, although 99% of scientists in the US concur that climate change is partly manmade, about 60% of Americans still fail to acknowledge the detrimental impact of our actions on the biosphere (The Age of Stupid 2009, min.24). This skepticism translates into procrastination of the progress towards a sustainable path, and has only allowed for the continuation of the vicious cycle of excessive consumption from non renewable resources.

One way to quantify environmental damage is by measuring green house gas (GHG) emissions released from the use of energy (manufacturing, transportation, housing, etc.), which comprises six main gases as listed in the Kyoto Protocol: carbon dioxide (CO_2); methane (CH_4); nitrous oxide (N_2O); hydrofluorocarbons (HFCs); perfluorocarbons (PFCs); and sulphur hexafluoride (SF_6) (GHG Protocol 2004). Using carbon dioxide equivalent (CO_2e) as a universal unit of measurement to indicate the releasing (or avoiding releasing) of different GHG against a common basis proves to be helpful for comparison purposes (GHG Protocol 2004).

Awareness and Action

The interplay between economic and population growth along with unsustainable consumption, have not only led to environmental degradation but also to social erosion. One way in which social erosion is observed is in the increasing gap between social classes. For instance, it is estimated that 20% of the richest population holds 74% of the world's income as of 2009 (Jackson 2009). Not only this, but 1.5 billion people live in precarious conditions. This means that one person in four does not have access to even the most basic needs, such as clean drinking water and sanitary systems (Home 2009, min.56). As Michael Moore points out, we are living in a system that enriches the wealthiest at the expense of the many (Capitalism: A Love Story 2009, min.129).
As these environmental and social problems have grown more visible, so has the awareness of the urgency to reach sustainability. Evidence of this new awareness is found in the adoption of sustainable ways of thinking. Therefore, one of the main tasks at hand for most industrialized countries and for emerging economies as well, is to significantly reduce the current levels of GHG emissions in the shortest term possible.

The Kyoto Protocol from 1997 is arguably the first global cooperation attempt to reduce GHG emissions. According to this international treaty, 37 countries along with the European Union commit themselves to reducing their GHG emissions by 5% against 1990 levels by 2012 (UNFCCC 2010). The wealthy nations (US, Canada, EU, Japan, Australia, and New Zealand) use the largest portion of resources, but emerging economies are expected to join (National Geographic 2011). Before this happens, it is imperative for the wealthy nations to set an example in the fight for sustainability. In particular, Canada being the second largest country in the world, enjoys a vast amount of natural resources while having one of the lowest population densities in the world

(CIA 2011). Despite this, Canada is one of the largest polluting countries per capita (IEA 2010). Canada signed the Kyoto protocol on April 29th 1998 with a commitment reduction target of 6% against the base year (1990) to be reached by 2012. According to Jaccard et. al (2003), it would have cost Canada between CDN$15 to CDN$45 billion to reach its Kyoto target by 2010 based on the estimations of two technology-explicit models, MARKAL and CIMS, respectively. However, despite the Kyoto commitment, the country experienced instead an increase of 27.4% GHG emissions from 1990 to 2008 (IEA 2010). When compared against the world, Canada has a higher aggregate intensity – absolute energy use per capita or per unit of GDP – than most International Energy Agency (IEA) countries, ranking second and fourth, respectively (NRC 2006). In the IEA report on GHG emissions, Canada makes the top 10 list of world polluters when measured in CO_2e emissions per capita, ranking 4th in OECD countries, and producing four times more CO_2e than the world´s average (IEA 2009). Due to these negative results, Canada negotiated a lower committed reduction of 3.3% in this climate change treaty (UNFCCC 2010). This shows on the one hand, the failure of a wealthy nation to set an example. On the other hand however, it shows that Canada comprises a large potential for improvement in the climate change mitigation context.

Two Options for Action

There are two main options regarding energy consumption: expanding/improving the energy supply towards renewable sources and decreasing consumption patterns. Extensive worldwide efforts are devoted to replacing or expanding energy supply from polluting sources (fossil fuels) to cleaner sources (renewable energies). Overall investment in clean energy grew 230% from 2005 to 2009, and $162 billion was invested globally in 2009 (The Pew Charitable Trusts 2010). In the long run, these efforts will unquestionably pay off, but conversion to renewable energies has been a rather lethargic process due to the high costs involved with the construction of new capacity. Simply put, it is much cheaper to continue burning fossil fuels; the infrastructure is in place and the resources are still relatively cheaper to pump out of the ground. In my view, replacing or adding new energy infrastructure results in higher patterns of consumption and waste. This is one of the reasons why I argue that a change in behaviour is an important component for success, and thus is examined in this study.

Contrary to the aforementioned, GHG emissions can also be reduced by decreasing human consumption patterns, particularly in large polluting areas as is the case for North American countries. By altering consumption patterns, significant GHG reductions can be realized, with immediate results in some cases. There are mainly two ways this can be done: changing efficiency and changing behaviour. For example, in 2005 the transport sector was the largest polluting sector in Canada, responsible for 36% of GHG emissions (NRC 2008), but with low vehicle retirement and replacement rates, it will take years for new technologies to significantly impact fuel usage, making investment in this sector relatively less effective. In contrast, simple driver behaviour changes such as slowing down or buying smaller vehicles at the time of purchase could immediately exceed the new car technology improvements (NEB 2009).

Decreasing consumption patterns has not been the preferred approach, in part due to the financial losses involved (the private sector has little or no incentive to push reduction practices as less consumption is bad for business) but also due to the complexity of changing human behaviour. This paper explores GHG emission abatement measures within this second alternative.

1.2 Research Problems

The three problems presented below have been formulated with the help of researching secondary data in the field of energy consumption, particularly in Canada, and inputs from own knowledge and experience. As such, this process follows the guideline presented by Arbnor and Bjerke (1997) named 'A plan for a Study That Determines Problems'.

A country like Canada that enjoys more abundant natural resources and a healthy economy (CIA 2011) is not only able to meet its basic needs, but also able to invest in ways of mitigating its negative impact on the environment. This points to the first research problem for Canada, and other industrialized countries, which is the high release of GHG emissions due to the continued reliance on fossil fuels as the main source of energy. Despite the fact that current technologies are sufficiently advanced to build a sustainable economy, in 2009 80% of the energy we consumed worldwide came from non-renewable sources (Home 2009, min.85). In regards to Canada, actually 89% of 2008 energy production came from non-renewables, which means that only 11% came from clean energy, namely hydroelectricity, wind, and wood (NEB 2009a).

The second research problem relates to the cost and time of upgrading the current stock of energy consuming technologies to more efficient ones. Following with Canada as the example, in 2008 the four main sectors of energy consumption were: industrial (48%), transportation (24%), commercial (14%), and residential (14%). Looking back at the four previous years, the sectors kept similar percentages (NEB 2009a). Although the residential sector in Canada consumes the smallest portion of energy, it is important to note that in the short term, the cost of upgrading the existing stock for the other three sectors is significantly higher than in the residential one (NEB 2009). Consumer behaviour has the greatest effect on energy use in the residential sector. It is here individuals have the best ability to control their energy consumption habits based on personal preferences and priorities. This is far less likely in the industrial and commercial sector" (NEB 2009).

This leads to the third research which issue involves human behaviour. The problem lies in the disconnect between knowledge and technologies available versus applications in practice. As previously mentioned, Canada has the technologies and resources to tackle its environmental degradation, however, most of the production and consumption still comes from non-renewables. In essence, "these are not technical issues as much as they are leadership issues" (The 11th Hour 2007, min.66). In other words, it comes down to a change in the individual's behaviour.

1.3 Justification

Given the environmental distress we face as a society, in a wide sense, this thesis represents a push for sustainability, an attempt to inspire others to research more, to take action, and to make a switch as individuals to renewables as the main source of energy. In a narrow sense, the thesis is designed from a residential perspective, to not only increase the level of awareness, but also the adoption rates of readily available projects that enhance the efficiency of energy consumption. In this way, the contribution of the thesis to the research field lies in showcasing a Cost Effectiveness Analysis (CEA) in the Canadian residential market as a method for the selection of such projects, integrating both environmental and economic perspectives at the same time. In addition to this, another contribution is the incorporation of a behavioural component as part of the analysis of the process of adoption.

Scientists agree that much of this environmental distress is caused by our human footprint (The Age of Stupid 2009, min.24). In my view, the justification for choosing the study on energy lies in two main factors. First, the sources of energy are mostly non-renewables although other options are available. Second, there is a lot of waste in the consumption of energy due to both, overconsumption and failure to adopt more efficient technologies. As such, one way to restore the equilibrium of the ecosystem we are dependent on is to tackle the issue of energy consumption.

The reason why this paper looks at Canada is because of two reasons, responsibility and response-ability. Regarding responsibility, Canada is part of the wealthy nations that uses more resources, including energy, than the world's average. In fact, a Canadian produces four times more CO_2e emissions than the world's average person (IEA 2010). As far as response-ability, Canada holds a considerable amount of resources, including natural, technological and financial. For instance, Canada invested $3.3 billion dollars in clean energy technologies in 2009 and ranked 8th in the top clean energy investment countries the same year (The Pew Charitable Trust 2010). However, this and previous investments in clean energy still represent only a minor percentage of the energy mix (NEB 2009a). This implies that it will take a significantly longer span to see the desired impact and reach of such investments. Yet, the current needs to solve the environmental distress demand faster action.

This urgency of actions and results lead to one of the reasons for selecting the residential sector as the main focus of the study. It is significantly more expensive to change technologies in other sectors (NEB 2009). This makes it even more attractive for research, investment and a push for change. Yet another reason, one with very large consequences, is that the residential sector involves the entirety of the population. As one may not be a direct participant in the commercial or industrial arenas, one is always a participant in the residential one. Consequently, this points to another reason: its efforts towards creating or increasing an environmental awareness are likely to cascade down to the other energy consuming sectors.

1.4 Purpose

The purpose of this paper is to aid the residential user in Canada or elsewhere in choosing between the many available conservation projects for their home. For this, 11 GHG emission reduction projects applicable to the residential sector will be examined. This will be done using a Cost Effectiveness Analysis (CEA) which encompasses both environmental and economical considerations at the same time. More specifically, the purpose is to provide a tool for the evaluation of CO_2e abatement projects in the residential sector, such that decision makers are able to compare available options, estimate their economic and environmental benefits, and ultimately increase their rate of adoption. Last but not least, the results of the CEA incorporate a behavioural component that affects decision making regarding the adoption rates.

1.5 Research Questions

Two research questions stem from the purpose of this thesis:

Q1. *Based on the CEA, what is the cost of being environmentally responsible within Canada's residential sector regarding the selected emission abatement projects?*

This question is designed to reveal the potential carbon emission reductions regarding the 11 abatement projects, in such a way that they are comparable at the margin. The results of CEA for each project are expressed in the same unit of measurement, namely a levelised cost per unit of emission reduction (CDN$/t CO_2e). In this way, they can be ranked by the residential user. The lower the cost, the more attractive the project becomes.

Q2. *Based on the CEA, from a behavioural perspective, what are some of the reasons of the current adoption rates of the Canadian residential sector regarding the selected emission abatement projects?*

The study of this question becomes necessary after looking at the cost of being environmentally friendly and observing large adoption potential for some of the presented projects. The aim of this question is to shed more light on possible reasons why a residential user may decide to invest or not in a particular abatement project.

1.6 Thesis Outline

Chapter 1, Introduction, presents the research context along with the problems, as well as the justification, purpose of the study, and the research questions. The thesis continues with chapter 2, Methodology, where the methodological view and methodical procedure are discussed. In addition, other information, such as CEA, abatement projects, and data sources and collection, and limitations are discussed. Chapter 3, Background Statistics, reviews some information related to Canada's energy production, use, and its housing composition. Chapter 4, Literature Review, is divided into three sections: energy consumption models, energy conservation models, and behavioural literature. Chapter 5, CEA, Behavioural Variables & Abatement Projects, presents CEA in detail, as well as the 11 abatement projects along with the behavioural variables considered. Chapter 6, Analyses and Results, starts with the environmental analysis, as the first stage of CEA. After, the economic analysis follows. At the end of this chapter, the two research questions are answered. The thesis is finalised with Chapter 7, Conclusion.

2. METHODOLOGY

Methodological View

Methodical Procedure

Source of CEA

Abatement Projects

Data Sources and Collection

Limitations of the Study

Chapter 2 encompasses information from the methodological view chosen to the limitations of the study. It starts with the justification of the methodological view, followed by the methodical procedure. After, the source of CEA and the abatement projects are explained. Next, the section that refers to data sources and collection is discussed. The chapter is finalised with the limitations of the study.

2 Methodology

2.1 Methodological View

According to Arbnor and Bjerke (2009, p.22), there are three basic methodological views or approaches in “the world in which we act as business economists”: analytical, systems, and actors. Each of them is situated within a continuum that goes from knowledge in order to explain to knowledge in order to understand. More specifically, the analytical approach fully incorporates knowledge in order to explain; the systems approach encompasses a combination of knowledge in order to explain and understand; while the actors approach integrates only knowledge in order to understand (Arbnor & Bjerke 1997).

As Arbnor and Bjerke (1997) argue, it is virtually impossible to determine the best methodological approach. One is not considered better than the other. This is because the view adopted depends highly on the characteristics of the study at hand, the desired outcome, and the researcher’s own opinion. I find the analytical approach as best fitted to the purpose of my thesis because of the following two reasons: objective (explained below) and descriptive nature (explained in 2.2).

Regarding objectivity, the “analytical approach assumes that reality is objective. Systems approach assumes that reality is objectively accessible. Actors approach assumes that reality is a social construction” (Arbnor & Bjerke 1997, p.54). In addition, the main assumption of the analytical approach is that “reality is filled with facts and independent from individual perceivers” (Arbnor & Bjerke 2009, p.36). Given these characteristics, the analytical approach is most appropriate because the pursued knowledge that stems from the CEA does not depend on individuals, but rather upon objective data, such as costs, GHG emissions, and adoption rates.

2.2 Methodical Procedure

The analytical approach comes in two types of study, explanatory and descriptive (Arbnor and Bjerke 1997). “There are a large number of studies that are of a purely descriptive character. The goal of these studies is to measure without trying to establish logical consequences of such measures” (Arbnor & Bjerke 1997, p.84). This is one of those cases, with the exception that although a logical consequence is not explained, a behavioural understanding approach is briefly integrated.

The descriptive analytical approach fulfills the purpose of showing the cost of being environmentally friendly in the case of the 11 abatement projects. This is because, I believe that the most appropriate way the residential users can understand and adopt new projects is by providing them with objective and descriptive information that best tries to represent reality. It is important to note that understanding is a part of the behavioural component and would require the adoption of another methodological approach. However, the main purpose is devoted to providing a description of the objective reality for the selected projects. In consequence, the behavioural component is embedded throughout the paper and used to complement the descriptive study.

As the method chosen for the analytical approach is a descriptive study, the following figure (Figure 2.1) will be used as guidance for this research.

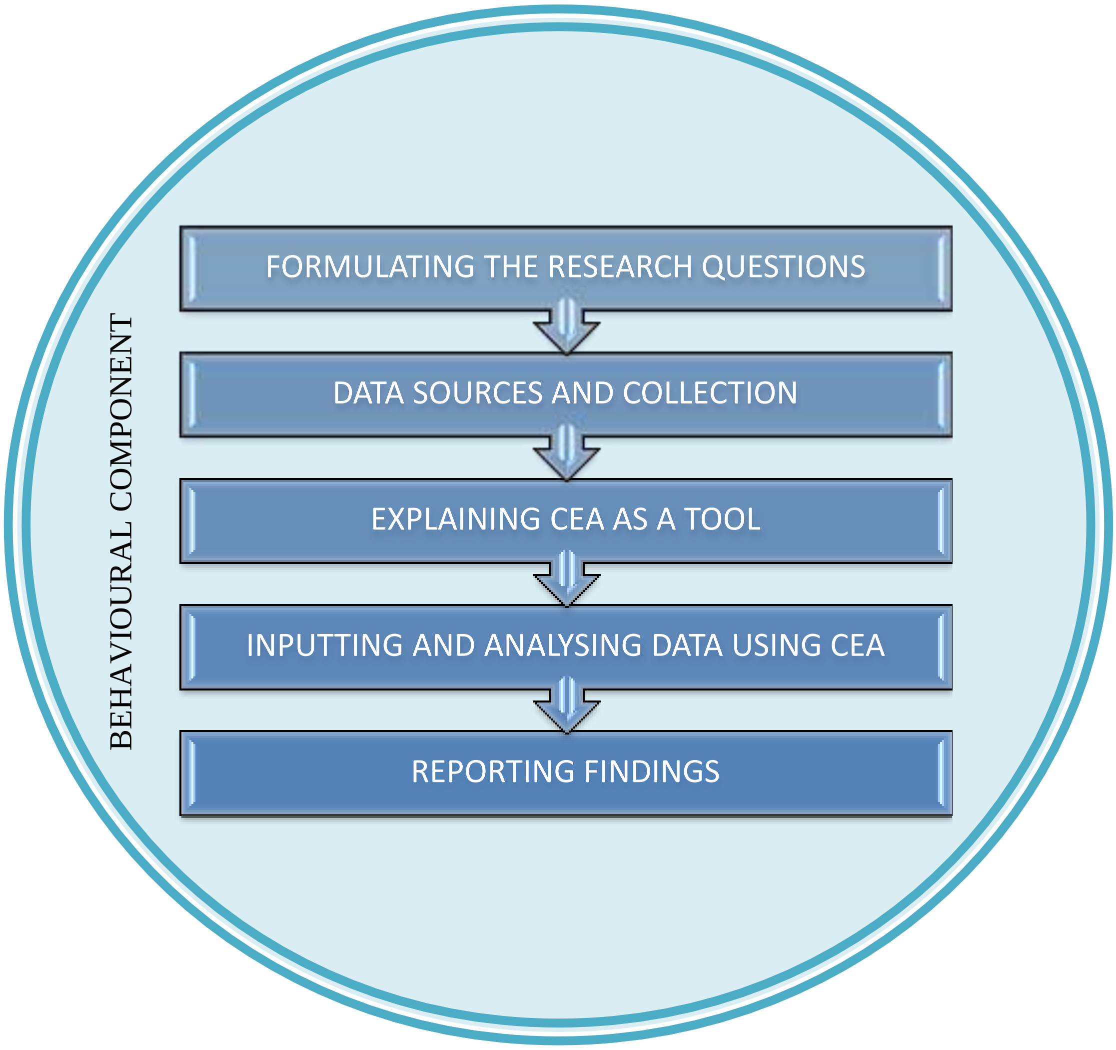

Figure 2.1 Plan for an Analytical-Approach Descriptive Study
(Source: Adapted from Arbnor & Bjerke 1997, p.334)

The first step, ***Formulating the Research Questions***, is discussed in section 1.5.
The second step, ***Data Sources and Collection***, encompasses researching environmental and economic data for each of the 11 emission reducing projects. This step is further developed in section 2.5 below. In the third step, ***Explaining CEA as a Tool,*** the Cost Effectiveness Analysis (CEA) yields a *levelised cost per unit of emissions reduction*, which is measured in Canadian dollars per ton of CO_2e reduced. The CEA is a tool that allows decision makers to rank the projects based on the results of the analysis process. In addition, it is applicable to other similar abatement projects. This step is developed in section 5.1. In the fourth step, ***Inputting and Analysing Data Using CEA*** (Chapter 6), the environmental and economic data collected are plugged into the CEA method to arrive to the final results. These results are useful for comparing the costs and benefits of each project at the margin, as they are expressed in the same unit of measurement. The research method plan finalises with the fifth step, the ***Reporting*** of the ***Findings***, which is also discussed in Chapter 6. It is important to mention once more that all steps incorporate behavioural considerations, in particular, the fifth step.

2.3 Source of CEA

The Cost Effectiveness Analysis used in this paper is part of a methodological framework for the economic evaluation of CO_2 emission reduction policies developed by Mirasgedis et al. (2004) for the residential sector in Greece. In that study, the authors employed a Cost Benefit Analysis (CBA), which goes a step beyond CEA. The main difference between CEA and CBA is that the latter integrates social costs in an attempt to make the study more useful for policy makers, whereas "CEA takes into account only the related net financial costs, thus highlighting win-win situations…by monetization of environmental benefits" (Mirasgedis et al. 2004, p.537)

CBA was not considered for the purpose of my study because of the following reasons. First and above all, it is much more difficult, not to mention controversial, to estimate social costs and benefits than to estimate environmental ones. This is arguably due to the fact that environmental degradation is more visible than social damage. With environmental degradation, measurements are possible, such as the release of CO_2e, soil damage, fresh water contamination, etc. In terms of social damage, while it may be possible to measure poverty for instance, it could be argued that those measurements can hardly be expressed in mathematical terms, much less be globally comparative. For example, a hypothetical oil and gas company starts exploring a gas field close to an aboriginal reserve. Although one could measure the economic impact and perhaps the environmental one as well, how does one go about quantifying the social change in the way the tribe lives their lives, when facing a loss of biodiversity, modernization, cultural change, etc. This is why the social aspect is so much more difficult for corporations to estimate and to report (Hubbard 2006). And second, I hold the assumption that the target audience for my study, which is mainly the residential users, is primarily interested in finding out its private costs and benefits of being environmentally friendly before the social ones.

The CEA presented in this paper closely follows the methodological framework presented by Mirasgedis et al. (2004). However, it is adapted to the Canadian residential sector. Apart from the exclusion of CBA, and the usage of Canadian data, another difference from the Greek study is the inclusion of a behavioural component throughout my research. This represents a contribution to the research field of energy conservation, apart from presenting CEA within a Canadian context.

2.4 Abatement Projects

Apart from selecting the residential sector in Canada as the main target for this research, a number of GHG abatement projects, also referred to as conservation projects, were considered as candidates for the next step.

A conservation project is the action of replacing, modifying, or upgrading an existing energy consuming or energy conserving element in a residential household for the purpose of reducing GHG emissions. This is also commonly referred to as a retrofit in the industry. The current stock is defined as the existing energy consuming or energy conserving element that relates to the abatement project. For example, an incandescent bulb is regarded as the current stock. A compact fluorescent light (CFL) bulb is regarded as the new stock. The process of replacing an incandescent light bulb for a more efficient, less energy consuming CFL bulb represents an abatement project.

Several conservation measures were chosen based my research on the current energy and resource consumption patterns within the sector. In more detail, consumption often falls under five categories listed from more to less consuming: space heating, water heating, appliances, lighting, and space cooling (NRC 2008). From my database of abatement projects, 11 were selected in such a way that they target the most energy consuming categories first. Also, they needed to be representative of energy conservation as well as resource conservation, which is the case for water. They could serve as a template for other abatement projects that are similar or complementary, or that may even include a change in behaviour. Yet another reason that affects the selection process involves data availability. The majority of the selected projects had the most available data from government reports and statistics. This factor becomes evidently important in the process of finding out the potential of emission abatement for each project, thus making the results more reliable. Regarding the assumptions of each abatement project, the information was collected from various conservation and corporate websites. Finally, these 11 conservation projects were chosen because throughout my research, I came to the conclusion they were the most widely discussed. Table 2.1 lists the conservation projects.

List of GHG Abatement (Conservation) Projects	
M1	Replacement of heating equipment
M2	Replacement of windows and doors
M3	Caulking and weather stripping
M4	Insulation around hot water pipes
M5	Installation of a programmable thermostat
M6	Installation of a solar water heater
M7	Heater blanket on water heater
M8	Replacement of toilet with dual flush system
M9	Installation of low flow showerheads
M10	Compact fluorescent lamp CFL
M11	Indoor clothes drying

Table 2.1 List of GHG Abatement (Conservation) Projects

2.5 Data Sources and Collection

Step two of the descriptive study plan addresses two issues: the sources of the data and its collection. The purpose of the study requires the collection and use of secondary data for various reasons. To begin with, primary data was not considered because it is prohibitly expensive to collect. Secondly, the information necessary for this study requires a wide range of data categories that have to go through different layers of calculations before it becomes useful. To illustrate, data collection falls under three main categories: housing, environmental, and economic data. Each of these data categories are dedicated a subsection of its own below. Finally, most of the information is available from reliable sources, such as governmental reports and statistics bureaus.

2.5.1 Housing Data

This category mainly refers to the building distribution that stems from a number of factors, such as housing type, climate, year of construction, etc. that affect the housing composition and its respective potential emissions reduction. For the purposes of this study, two of those factors have been chosen, the housing type and year of construction. The housing types in Canada are defined into four distinct categories: detached houses, double/attached houses, apartments, and mobile homes. Likewise, the time of construction is divided in three different periods: before 1969, 1970-1989, and 1990-2007. Alongside the housing composition, there is also housing data that describes the implementation potential for the abatement projects in average values.

The housing data is used to calculate the penetration rates available for each of the conservation projects. The penetration rate can be defined as the number of units of a particular project that can be performed in a household. For instance, the number of incandescent light bulbs per household that can be replaced by CFL bulbs. This data is used as input in the first step of CEA, the environmental evaluation.

The housing data was collected from Natural Resources Canada's housing statistics, a government bureau. The housing composition data is summarized in Appendix 1.

2.5.2 Environmental Data

Arguably, the environmental data could be referred to as technical data because it encompasses many technical measures, including: the average energy consumption per period, type of energy required, the estimated lifetime, the required maintenance, the efficiency rates, GHG emissions either directly or indirectly, and any other pertinent figures that aid in the arrival to the intended measure, namely the release of GHG emissions.

The environmental data is used as input in the first step (environmental evaluation) to calculate the release of GHG emissions of the current stock and the potential reductions of the conservation projects, yet it is also used throughout the rest of CEA. This data shows the potential environmental benefits as well as the energy savings from retrofitting the current dominant stock. The information from the environmental analysis is used to calculate the technically feasible emissions reduction for each individual project found in Table 6.2.

The environmental data was gathered either directly from manufacturers or suppliers, or from previous studies and governmental sources. When necessary, the data was converted into the same unit of measurement in order to make it comparable between old and new stock.

2.5.3 Economic Data

The economic data refers to all the costs and monetary benefits that stem from adopting a conservation project. The cost of equipment, upgrades, installation, maintenance, parts, etc. are all examples of it. The economic data is used as input in the second stage (economic evaluation) to provide cost-effective indicators for the adoption of the appropriate replacement inventory of the current stock, yet it is also used throughout the rest of CEA. The calculations of the economic analysis are found in Table 6.3. Much like the environmental data, the economic data was gathered either directly from manufacturers or suppliers, or from previous studies and governmental sources, as well as energy service providers.

2.6 Limitations of the Study

One limitation of this study regards the use of secondary data. Although data gathered from government sources, such as statistics bureaus and government agencies is commonly regarded as reliable, the same may not apply for data collected from private sources, such as manufacturers or service providers. Assuming that is the case, the private sources may provide less reliable and possibly biased information. The ideal way this limitation can be addressed is by collecting primary data for the proposed conservation measures. The collection of primary data would help in developing statistics that can enhance the validity of the results found in this study.

Another limitation relates to the exclusion of factors that affect the different housing categories, such as climate zones, floor space, etc. and their interaction to the calculations of the emission potential reduction. It would require a much larger study and the use of robust statistical methods to incorporate all these other variables.

One more limitation regards the behavioural considerations, which in this study are incorporated using a descriptive basis. However, it is possible to integrate them as variables in a study that incorporates statistical analysis rather than a cost effectiveness analysis. The reason why statistical methods were not included in this study is because expressing a behavioural component in mathematical terms is controversial, as well as it is better fitted with the use of primary data.

Besides the previous limitations, another one concerns the exclusion of social costs related to the environmental problems faced by Canada, and all other countries for that matter. The integration of cost benefit analysis to this study would, in my view, reinforce the stated results. Nevertheless, in order to make the study better suited for policy makers, it is recommended to attempt to incorporate CBA, and this is another suggestion for further research. However, as my target audience is mainly the residential users, I hold the assumption that CEA is sufficient to serve the purpose of my study.

Last but not least, it can be argued that a limitation exists regarding the number of conservation projects chosen in this study and the assumptions of each project. As it stands now, there are a disproportionate number of projects for each of the energy consuming categories in the Canadian residential sector. Yet, as previously mentioned, the chosen projects reflect the priorities of the sector. Additionally, there are multiple other conservation projects that can be studied in a similar fashion using the method employed in this study. The assumptions for each project (Section 5.3.1) are based on private secondary data from multiple conservation and corporate websites. Primary data is recommended for a more robust analysis.

3. BACKGROUND STATISTICS

Canada's Energy Overview

Canada's Housing Composition

Chapter 3 includes some background statistics on Canada regarding its energy production, use, and its housing composition, as information necessary to assess before moving to the next chapter.

3 Background Statistics

3.1 Canada's Energy Overview

Regarding the energy source, Canada produced 17,757 Petajoules (PJ) in 2008, 39.4% from petroleum, 35.1% from natural gas, 8.2% from coal, 7.5% from hydroelectricity, 6.1% from nuclear, 3.5% from wood and pulp, and 0.1% from wind. As seen in the Figure 3.1 below, the red shades indicate non-renewable sources, which account to 87%, whereas clean sources, represented by the green shades, account for 11% (NEB 2009a).

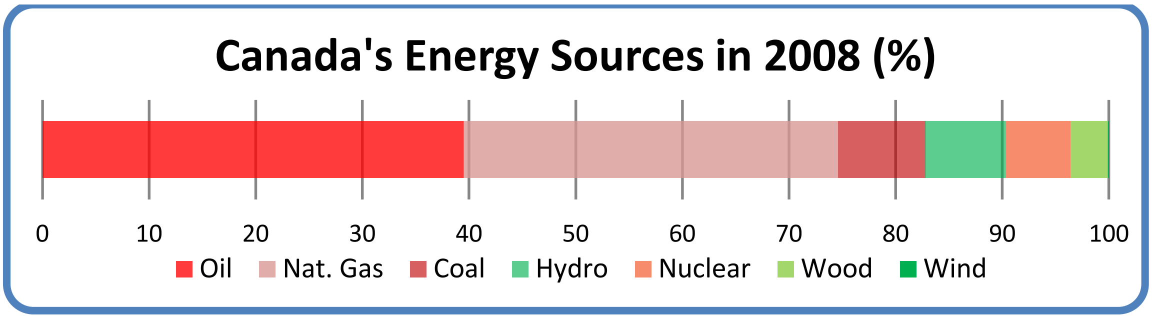

Figure 3.1 Canada's Energy Sources in 2008. *(Source: NEB 2009a)*

Regarding the energy consumption, from 1990 until 2007, it increased by 28%, from 6936.3 PJ to 8870.5 PJ (NRC 2009). The corresponding GHG emissions, expressed in Megaton (Mt) of CO_2e were 432.5 and 550.9, a 27.4% increase (IEA, 2010). During the same period, the Canadian population grew by 19% (approximately 1% per year), and GDP increased 58% (more than 3% per year) (NRC 2009). Figure 3.2 below charts these trends from 1990 to 2005. Growing economic conditions and population have made it difficult to achieve reductions in energy use and GHG emissions.

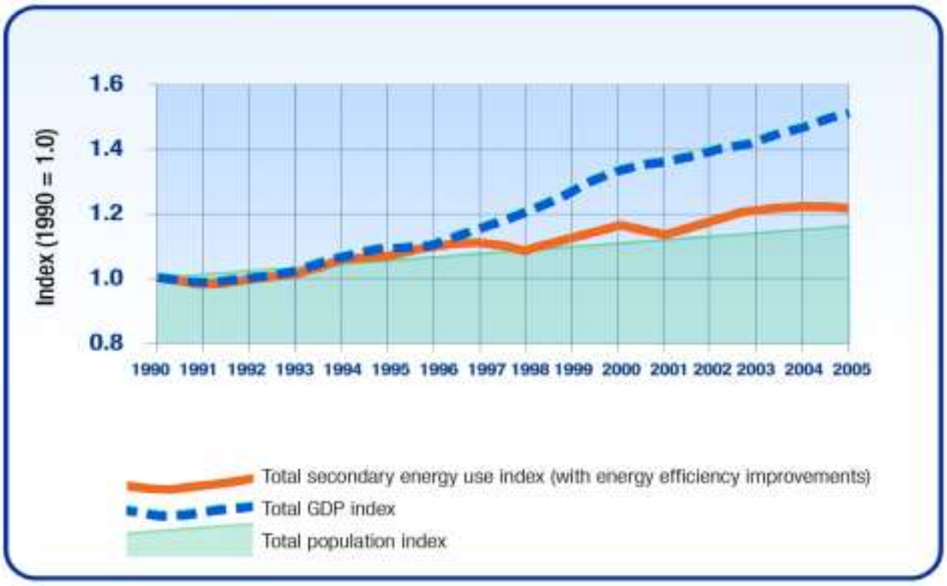

Figure 3.2 Total Secondary Energy Use, Canadian Population, and GDP 1990-2005 *(Source: NRC 2008)*

Residential energy accounted for 16% (1447.2 PJ) of secondary[1] energy used in Canada and 15% (74.3 Mt CO_2e) of GHG emitted in 2007 (NRC 2009). Although, the industrial and transportation sectors use twice or more energy each than the residential sector, the latter represents large potential for short term improvements when behaviour changes are considered as means of reducing consumption patterns. Industrial and transportation stock are not easily or inexpensively replaceable as it may be for the residential one.

Figure 3.3 shows the energy consuming categories for the residential sector in 2005. A surprisingly large portion, 78% in total, went to satisfy space and water heating (see Appendices 3 and 4). In 2007 this number jumped to 81% (NRC 2009). These figures may be justified in part due to harsh Canadian winter conditions. Nevertheless, these numbers also show that the current systems are inefficient. Countries with similar weather conditions such as Sweden used 61% of residential energy for space and water heating in 2009 (SEA 2010).

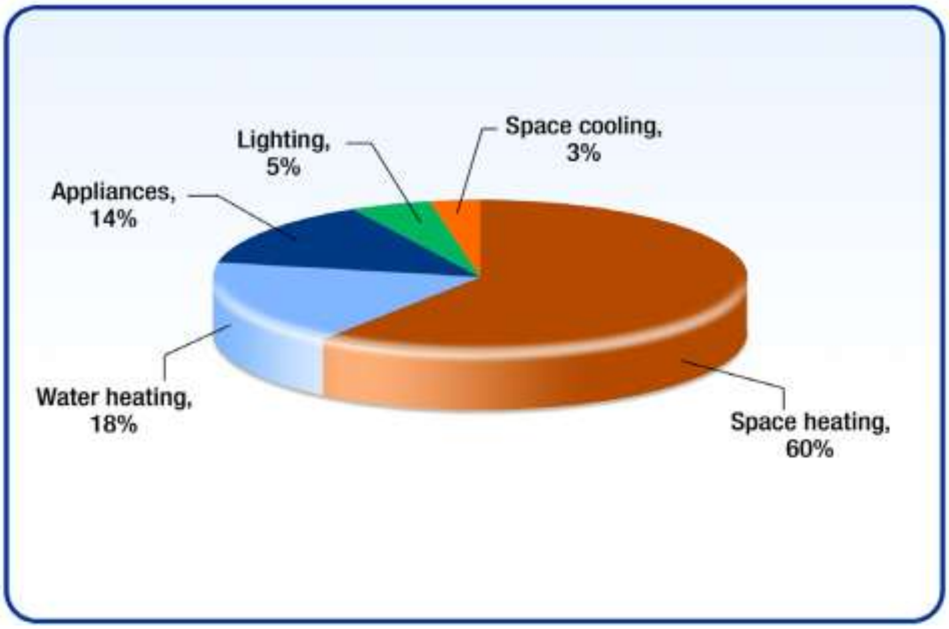

Figure 3.3 Distribution of Residential Energy Use by End-User in 2005 *(Source: NRC 2008)*

However, energy improvements in Canada are helping revert some negative trends. For example, the average energy intensity per household in Canada has decreased by 14% compared to 1990 levels, and energy efficiency (improvements on the property) increased by 29% (NRC 2009). Although, the adoption rates of conservation projects are increasing, Canada´s emission reduction potential is still very large.

It is important to note that the two major energy sources for the Canadian residential sector are natural gas and electricity. Together they amounted to 86% of all residential energy use in 2005, namely 47.2% and 38.5%, respectively (NRC 2008). Natural gas is a fossil-fuel and thus, it represents a non-renewable source. Electricity, depending on how it is generated, is potentially a clean solution to satisfy energy needs. In Canada's case, electricity is produced by both conventional ways and clean technologies, as seen

[1]Secondary energy is the energy used by final consumers, and does not include pipeline, producer consumption and transfer, and energy losses (NRC 2008).

in Figure 3.4 below (NEB 2009a). As it can be observed, 85.2% of electricity was generated using clean technologies (hydroelectricity, thermal, wind and tidal) and 14.8% came from a conventional source (nuclear) in 2008. Although this indicates a positive aspect, only 32.7% of the clean electricity produced is used by the residential sector (NEB 2009a).

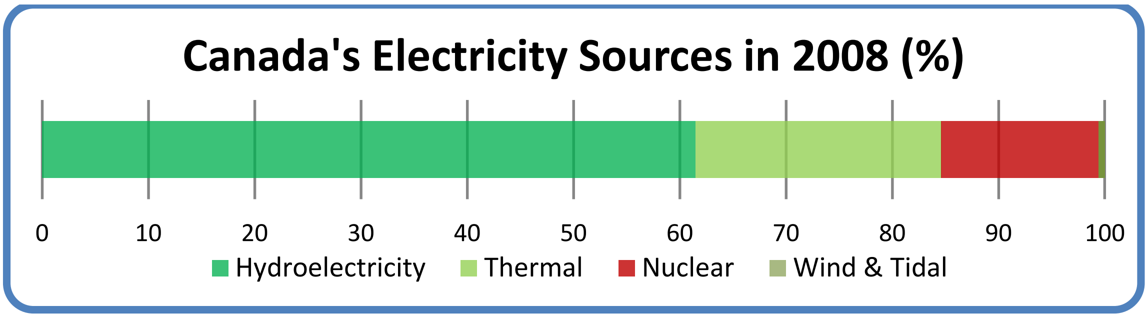

Figure 3.4 Canada's Electricity Sources in 2008 *(Source: NEB 2009a)*

To summarize, the energy trends and corresponding GHG emissions since 1990 have been marked by steady increases in the demand for energy, which contrary to the goals set by the Kyoto Protocol.

3.2 Canada's Housing Composition

Different dwelling characteristics affect the amount of energy that is necessary to satisfy the demands of their inhabitants. Particularly, building size (floor space), age, and type affect the energy intensity of each household. Energy intensity is defined as the amount of energy consumed per household (Mirasgedis et al. 2004).

In regards to housing size, the trend for Canada since the 1940s has been marked by the construction of larger dwellings. For instance, the average went from 126 m^2 in 1990 to 149m^2 in 2005 (NRC 2008). Another important factor that affects energy savings potential regards the age. Nearly 40% of the Canadian dwelling stock was 40 years old or more in 2007 (NRC 2008). This is important because when aging properties are not retrofitted for damage caused by natural deterioration of key components (such as windows and doors, building envelope, and all-around insulation), the resulting energy efficiency is substantially reduced. Likewise, older building stock had more relaxed construction codes in regards to energy conservation whereas newer stock incorporates more efficient designs. In regards to the building type, single detached households in Canada comprise nearly 60% of the total stock (see Appendix 1), but they represent 75% of the total residential energy consumption (see Appendices 2, 3, 4, and 5). This is mainly due to larger floor space per property and the fact that they do not share any walls with other properties.

Another factor in the Canadian residential sector composition, which is addressed in the behavioural component, is the proportion of ownership versus renting, where ownership is significantly higher for detached housing (95%) than for attached (70%) and apartments (34%). The highest levels of disposable income are also found in the single detached category. All these factors point out the single detached dwellings as the main candidate for conservation projects.

Other trends such as an increase in the number of appliances, or the number of people per household also affect residential energy use. Between 1990 and 2007, population in Canada grew 19% (5.3 million people), and 3.1 million households were added, an increase of 31% (NRC 2009). This particular trend can be explained by higher disposable income due to economic growth, an aging population that chooses to stay at home, and more of the younger population moving into single person households (NRC 2009).

The implications of these higher energy using factors and their combined effect help explain the previously mentioned increases in energy use for the sector. Figure 3.5 summarizes some of the major trends:

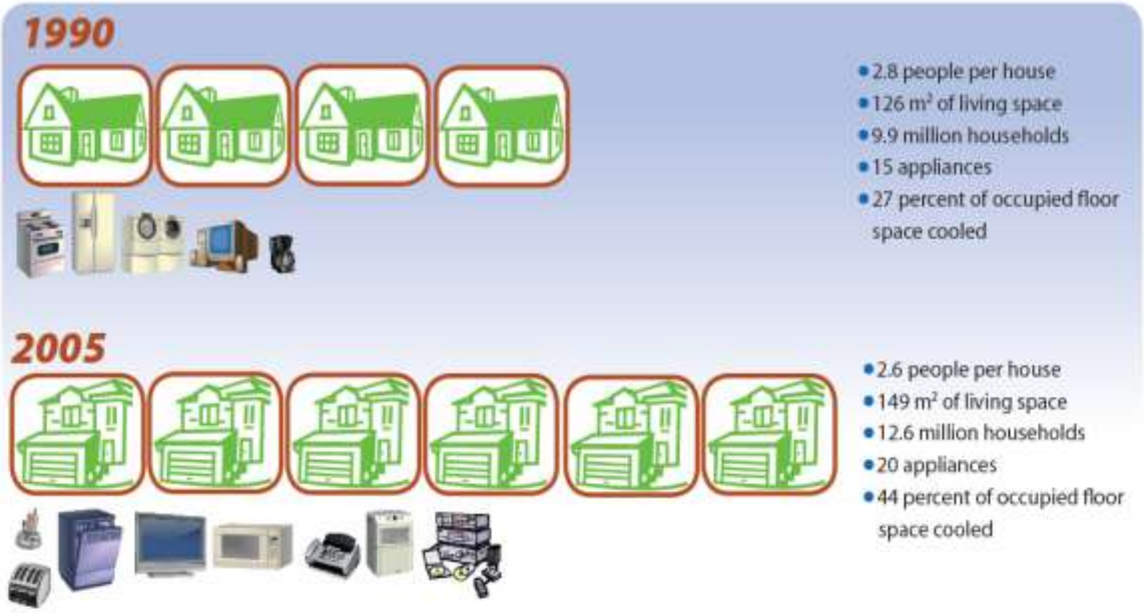

Figure 3.5 Residential Energy Indicators 1990-2005 *(Source: NRC 2008)*

4. LITERATURE REVIEW

Energy Consumption Models

Energy Conservation Models

Behavioural Literature

Chapter 4 includes the literature review regarding energy consumption and conservation models as well as research related to the behavioural component. Some energy consumption models are presented first. The chapter continues with the review of energy conservation models, after which patterns of energy conservation behaviour, levels of energy savings opportunity, and energy conservation and investment behaviours are discussed.

4 Literature Review

As mentioned in the introduction, there are two options for action. This paper focuses in the second option of decreasing energy consumption patterns. The residential literature often studies the energy subject from two opposite sides: energy consumption and energy conservation.

4.1 Energy Consumption Models

There are multiple modeling tools utilized to predict energy consumption in a country or sector of the economy. These models are useful not only in predicting the future consumption of energy, but also in estimating the associated GHG emissions. These types of models are critical for policy making and the design of environmental action plans.

In the residential sector, there are two approaches for predicting energy consumption: top-down and bottom-up models (Swan & Ugursal 2009). The main difference between the two is that the top-down approach "is not concerned with individual end-uses… [it] utilizes historic aggregate energy values and regresses the energy consumption of the housing stock as a function of top-level variables such as microeconomic indicators (e.g. gross domestic product, unemployment, and inflation), energy price, and general climate" (Swan & Ugursal 2009). On the contrary, the bottom-up approach starts from individual households in the forecasting of energy consumption. The CEA method used in this thesis is similar in its characteristics to the bottom-up approach as the study stars from data collected at the individual level.

Regarding this latter approach, it can be said that there are three distinct methodologies: the Engineering Method (EM), the Conditional Demand Analysis (CDA), and the Neural Network method (NN) (Swan & Ugursal 2009). EM forecasts energy consumption using very complex energy simulation systems based on a representative household sample, detailed housing characteristics, and user expertise. "CDA is a regression-based method" that requires a larger sample of households but information that is not as detailed, fact that makes it easier to develop than EM; however, with CDA, socio-economic parameters can be incorporated into the analysis (Aydinalp et al. 2001). Compared to the previous two models, the Neural Network model is capable of incorporating a large number of parameters and determining causal relationships (Aydinalp et al. 2001). The same authors (2001) performed a study in the residential sector in Canada using the NN model and concluded that its prediction performance is significantly higher than that of EM. Not only this, but socio-economic factors were also tested and the results were as expected (Aydinalp et al. 2001).

4.2 Energy Conservation Models

> *"Domestic energy consumption represents one area where the links between global environmental problems and individual behaviour are clearly identifiable, even if consumers do not immediately recognize the connection...However, the promoters of energy conservation face a major problem: how to increase the visibility of domestic fuel consumption in homes and increase peoples' awareness of the links between their behaviour and problems such as global warming…" (Brandon & Lewis 1999)*

As the purpose of my research is energy conservation, the focus of the literature review falls under this section of energy conservation models.

4.2.1 Why Conservation Models are a Tool for Action

Energy conservation models are tools designed to help make that connection, to show current consumption and the potential reductions, as mentioned in the previous quote. According to Steg (2008), there are three main barriers in achieving energy conservation: “insufficient knowledge of effective ways to reduce household energy use, the low priority and high costs of energy savings, and the lack of feasible alternatives”.

In my view, one of the core reasons why people believe conservation is expensive (second reason above), is lack of information regarding energy cost and insufficient energy knowledge (first reason above). This view is also goes in accordance with that of Sviokla´s (2008), who believes that “the easiest, cheapest, and fastest way to improve energy usage…would be to simply make cost of use more visible[…]If we could increase the pain of paying and make energy consumption of all types more visible, consumption will drop”. In essence, the following chapters serve this purpose. They make energy costs and benefits more visible and inform the residential user about the costs and benefits of various conserving projects.

Sviokla (2008) also stresses the fact that technology is essential in this fight, and we have to use it in order to make everything more visible. Further, he highlights that the technology we have available has not been fully utilized, and until we do so, the energy consumption will still increase. One use of current technology refers to the creation and use of conservation models, as the one in my thesis. Another use of technology is in linking goal setting with feedback for the purpose of reducing energy use, as shown in a study by Van Houwelingen and Van Raaij (1989). They theorize that goal-setting together with daily electronic feedback lead to a reduction in energy use, which their study subjects experienced even after one year. The important message here is that electronic daily feedback was found to lead to a greater energy reduction than a monthly external feedback or self-monitoring system.

4.2.2 Conservation Models

In a study named *Energy and associated greenhouse gas emissions from household appliances in Malaysia*, Saidur et al. (2007) focus their study on potential reductions of GHG emissions in the residential sector of Malaysia. The authors develop a method that uses several mathematical formulas for estimating the energy consumption and savings, and corresponding GHG reductions for the period between 1999 and 2015. In more detail, their method begins by estimating the energy consumption of appliances; this step requires data on the appliance’s ownership levels, utilization hours, and power rating. Next, Saidur et al. (2007) proceed to calculate the GHG emissions from the supply side, meaning the fuel mix that is required to generate the electricity that will power the chosen appliances. Their following step involves the estimation of energy savings and thus the emission reductions attainable if energy efficiency standards were introduced in Malaysia. Their study identified the major energy-consuming appliances and “the results show that significant amount of energy can be saved and thus huge volume of toxic emissions can be controlled” (Saidur et al. 2007).

Another model that is particularly designed for decision making is outlined in Mirasgedis et al. (2004). “This paper outlines a methodological framework for the economic evaluation of CO_2 emissions abatement policies and measures in the residential sector, taking into consideration both economic and social costs/benefits” (Mirasgedis et al. 2004). His framework is based on two stages: first the use of Cost Effectiveness Analysis (CEA) of several conservation projects in the Greek residential sector to calculate win-win situations within the private sector. Next, the estimation of social costs or externalities is incorporated through a Cost Benefit Analysis (CBA) of the same measures. The end result shows the cost of environmental benefits that stem from the adoption of such projects.

The results from Mirasgedis et al. (2004) state that 45% of the calculated potential emission reductions can be achieved through win-win situations, meaning that “interventions that present an economic benefit for end users without the need of any economic support policies” while another large percentage “will improve the general social welfare” if the social costs are incorporated (Mirasgedis et al. 2004).

The framework of Mirasgedis et al. (2004) is the backbone of the study presented in my paper. It is similar in the use of CEA to monetize the environmental benefits, as well as in the use of energy conservation projects in the residential sector. However, there are two main differences between the Greek study and the present thesis. First, Mirasgedis et al. (2004) incorporate the cost of externalities into CBA whereas, my study stops at the use of private data using CEA; and second, my paper incorporates behavioural considerations whereas Mirasgedis et al. (2004) limit their study to the techno-economic variables.

4.3 Behavioural Literature

“The economic analysis considers the cost-effective options assuming that consumers make rational, informed purchasing decisions based on a life-cycle cost analysis; yet many consumers do not take the most economic option for a variety of reasons” (NEB 2009). To not include behavioural considerations would limit the accuracy of forecasts and therefore a purely economical analysis may prove to be incomplete. As an example, compact fluorescent lamps (CFL) have been promoted for almost three decades in Canada, yet it is only recently that the majority of homes can claim more than one installed CFL (NEB 2009), and they remain an inexpensive and significant carbon footprint reduction measure available for implementation.

By bringing behavioural considerations to the consumer’s awareness level, along with the realization of the economic and environmental benefits of adopting particular conservation projects and behaviours, it may be possible to increase the adoption rates of such conservation measures and thus, help reduce excess or waste in consumption patterns. Although, the Canadian population is generally aware of climate change and the global environmental degradation, there is still a large gap between awareness and action. The following sections present an overview of behavioural considerations.

4.3.1 Patterns of Energy Conservation Behaviour

There is a myriad of variables that influence the likelihood of engaging (or not) in conservation projects. Simply put, there are people more likely to conserve than others. In the views of Van Raaij and Verhallen (1983), they based their study on two main aspects of energy, home temperature and ventilation. It distinguishes between five patterns of energy-related behaviour: conservers, spenders, cool, warm, and average. Conservers and spenders are the extremes the authors have identified. While the former use low temperature and low level of ventilation, the latter does the opposite. They represent the lowest and highest energy consumers, respectively. The warm segment uses “a high temperature and a low level of ventilation” while the cool segment uses the reverse, “a low temperature but a high level of ventilation”; for both, the energy consumption is seen as intermediate. The last segment, the average, refers to a group that “by definition is not deviating in its characteristics […] An attempt should be made to move this segment in the direction of the conservers” (Van Raaij & Verhallen 1983).

While these authors consider energy-related behaviour as contingent on other behaviours in the household (such as recreation, child care, and chores), D. Leonard-Barton (1981) considers upbringing and values in her voluntary simplicity theory, and argues that there are three types of individuals: conservers, crusaders, and conformists. “Conservers are people who have been brought up in a home with a very strong prohibition against waste of all kinds. Often someone in the household has lived in a developing country, or has experienced poverty as a child. Conservation is a way of life, both because frugality is habitual and because it is economic” (Leonard-Barton 1981). “Crusaders may have come from a family with a strong conserving ethic, but the motivation to engage in voluntary simplicity behaviours is born of a strong sense of social responsibility, more than out of a desire to save financially” (Leonard-Barton 1981). “Conformists are people who engage in voluntary simplicity behaviours for less well-defined reasons. They are less likely to buy second-hand clothes or goods, but they dutifully recycle resources, cut down on meat consumption, etc. Some are apparently motivated by guilt at being so comparatively wealthy; others have been influenced by voluntary simplicity adherents in their neighborhood” (Leonard-Barton 1981). The author concludes that many voluntary simplicity behaviours are in direct relation to a reduction in energy consumption and an interest in the adoption of at least one conservation measure.

Consequently, becoming aware and recognizing the different types of attitudes and behaviour towards energy conservation is necessary in order to find an approach that increases motivation and changes conservation habits. In my view, the process of energy conservation begins with this behavioural awareness. The next step is to assess the energy saving opportunity.

4.3.2 Levels of Energy Saving Opportunity

In general, one could say that individual consumers often compare and adopt available retrofit options using mainly economic considerations. This is labeled as the rational-economic model, in which “individuals systematically evaluate alternative choices…and then act in accordance with their economic self-interest. This model suggests that in order to influence these decisions, one needs only to inform the consumer of the financial advantages of particular choices and consequently the public, being 'rational', will act accordingly" (McKenzie-Mohr 1994). According to a study from the National Energy Board in Canada (NEB 2009), demand analysis includes two primary criteria, namely technical and economic feasibility. "A technical analysis for energy savings examines the substitution of the dominant existing stock (e.g., device, appliance, equipment, building, and vehicle) with the best available technology on the market, and the subsequent energy savings" (NEB 2009). Savings of 50% are commonly observed when judged against the most efficient new options, and thus considering only the technical considerations may overestimate the results (NEB 2009). This is followed by an economic evaluation that considers demand trends and scarcity constraints to the study, such as replacement or investment costs, financing options, feasibility, etc., resulting in more comprehensive results useful in determining the adoption rates of a particular conservation project. However, some studies include the influence of human behaviour as a central role in decision making. This is because *"the behavioural element becomes a defining factor between what is possible and what is plausible"* (NEB 2009). Figure 4.1 below indicates a theoretical level of the likelihood of adopting energy saving projects based on these three evaluation criteria (technical or environmental, economic, and behaviour-related or achievable).

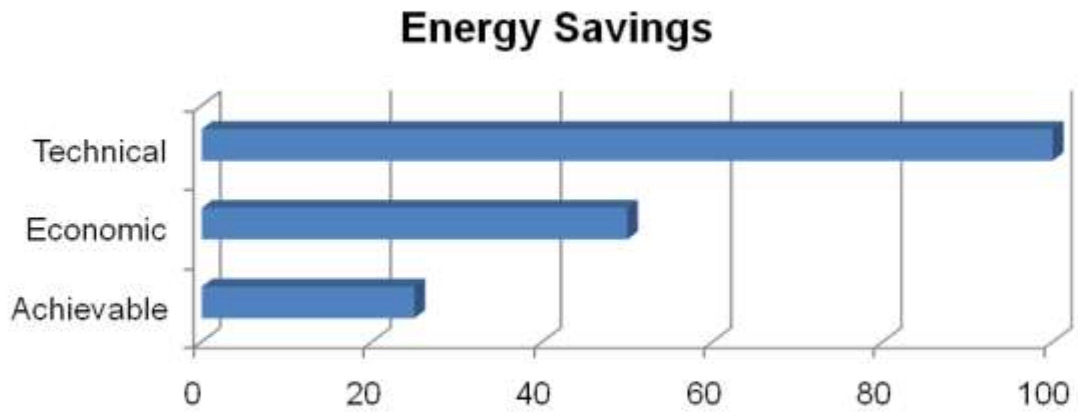

Figure 4.1 Levels of Energy Saving Opportunity *(Source: NEB 2009)*

The figure illustrates that the energy saving potential is largest when only technical analysis is considered. This potential is reduced when economic considerations are taken into account at the same time. Furthermore, when a behavioural component is added to the other two, the potential decreases even more. This emphasizes the importance of incorporating a behavioural component to the energy conservation analysis. In my view, the theoretical illustration above exhibits the difficulties and challenges that a residential consumer may be facing in the decision making process of adopting conservation projects. These difficulties and challenges depend on the individual's awareness of each level, whether he or she properly assesses each level separately and together with the others, and the priority assigned to each level. The assigning of more or less priority will lead to different results regarding energy savings.

4.3.3 Reducing GHG Emissions through Energy Conservation and Energy Investment

In order to achieve the previous, McKenzie Mohr (1994) distinguishes between three forms of resource-use behaviour: investment, management and curtailment. Similarly, Canada's National Energy Board (NEB 2009) study offers another classification, namely energy conservation, efficiency and investment.

Combining the previous two theories and rearranging their labels, I propose a slightly different classification in this paper for the purpose of studying (and reducing) energy demand. This new classification of resource-use behaviour distinguishes between energy conservation and energy investment.

Energy conservation "is generally seen as a reduction in level of output or service by deliberately using less energy. Often this means simply modifying usage to reduce waste (NEB 2009). Energy conservation can take two forms, management and curtailment. *Management*, as defined by McKenzie-Mohr (1994), explicitly relates to being more resource-efficient by making changes in behaviour. For example, setting back the thermostat each night or turning off the lights when not needed. *Curtailment*, "involves reducing amenities or comfort (McKenzie-Mohr 1994). Lowering the thermostat while in the house, or biking to work when private transportation is available are two examples of curtailment (McKenzie-Mohr 1994). Management and curtailment are almost exclusively behaviour related. In my opinion, changes in attitudes and behaviour towards energy conservation represent the largest potential for GHG emissions reduction in Canada, but it is perhaps the trickiest to implement as it involves changing behaviour and in some instances, a reduction in the level of comfort. This is because *"as any student of human behaviour knows, there is often a large gap between an attitude and an act"* (Leonard-Barton 1981). People know that smoking is harmful, yet many still choose to smoke.

Energy investment can take the form of *Energy Efficiency* where conservation projects with new or better technologies are adopted, "essentially getting the same output or level of service for less input energy" (NEB 2009). Household insulation or replacing an incandescent light bulb with a compact fluorescent lamp (CFL) are examples of energy efficiency. Investments can also be made in (added) *Capacity*. "This type relates to changing energy sources or generating on-site renewable energy where it does not change either the energy input or output but replaces one form of energy with another. Installing a solar panel on your home for water heating replaces natural gas or other fuels which would have been used to heat the water" (NEB 2009). "Investment requires a once-only change in behaviour", whereas management and curtailment "require both initially changing the behaviour and then maintaining that change over time" (McKenzie-Mohr 1994). For this reason, the author argues that conservation behaviours have less of an impact upon reducing resource use than that of investment. Unlike curtailment, and sometimes energy management, investment does not alter the level of comfort (McKenzie-Mohr 1994). For these particular reasons, energy investments are easier to target and motivate their adoption. Nevertheless, there is an evident financial tradeoff between energy conservation and energy investment where the latter requires a larger monetary investment. Figure 4.2 summarizes the previous classification.

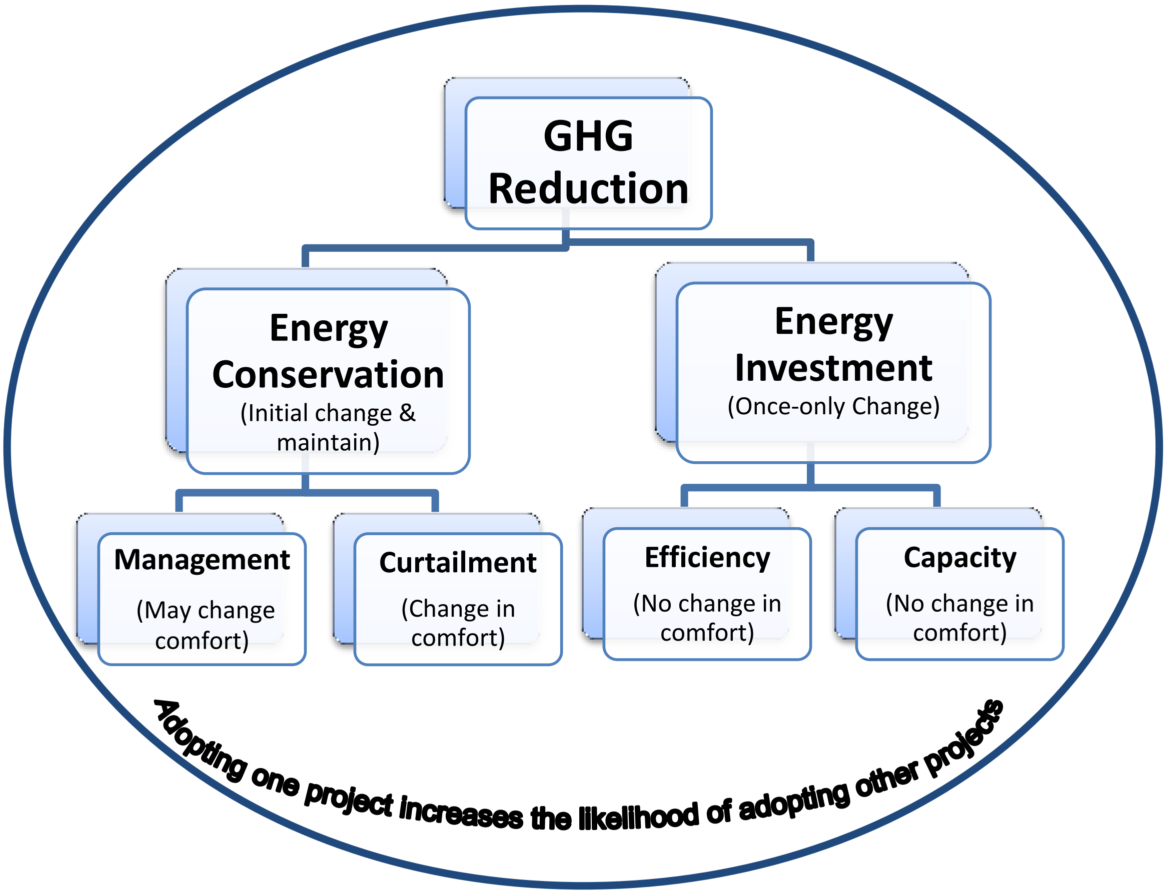

Figure 4.2 Energy Conservation and Investment Behaviours

Regardless of which choice is adopted, one does not need to choose one (investment) over the other (conservation), as they are not mutually exclusive. “Canadians are increasingly interested in the impact of energy and our environment. More and more, one cannot be mentioned without the other in mind” (NEB 2009). Changes in attitudes and behaviour are becoming widely accepted. To illustrate, in a society structured around high and individualistic resource use, as is the case of driving to work in Canada, a person may choose to bike or walk (curtailment) even if it already owns a fuel-efficient vehicle (investment) (McKenzie-Mohr 1994).

Furthermore, once a residential user adopts an energy conservation project, he or she is more likely to spread the word, explore other projects, or both. “Once a homeowner has engaged in a retrofit, and realized the savings that have occurred as a result of the investment, she is likely to be ready to adopt other conservation devices as well as advocate conservation to others” (McKenzie-Mohr 1994). One way to measure whether changes in attitudes and behaviour are successfully implemented is by observing in a sector, industry, or country, an incremental plan of adoption of conservation measures where the perceived pay-off or benefits are clearly demonstrated (Leonard-Barton 1981).

“Information changes behavior - all we need to do is make it transparent”
Sviokla (2008)

5. CEA, BEHAVIOURAL VARIABLES & ABATEMENT PROJECTS

Cost Effectiveness Analysis (CEA)

Behavioural Positional Variables

Abatement Projects

This chapter describes the method used to analyze and evaluate 11 GHG abatement projects within Canada´s residential sector. CEA determines the cost of their environmental benefits and ranks them on that basis. An attempt to bring the abatement projects closest to the achievable level is made by incorporating three behavioural positional variables. In addition, assumptions about the 11 projects are also summarized.

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5 CEA, Behavioural Variables & Abatement Projects

5.1 Cost Effectiveness Analysis (CEA)

CEA is a methodological background distinctively developed for decision making (Mirasgedis et al. 2004). Under CEA, all potential private gains and losses from a given project are identified, translated into monetary values, and compared on the basis of decision rules to determine if the proposal is desirable (Nas 1996). The resulting outcomes can be ranked based on the net financial costs related to the project (Nas 1996; Mirasgedis et al. 2004). Similar in most aspects to a cost benefit analysis (CBA), CEA ignores all external and social costs and benefits due to the complexity of estimating these externalities. The results from the CEA compare the costs of reducing CO_2e emissions and identify which investments should be prioritized by energy consumers. If a project shows a net benefit (negative cost), it is definitely worth approving (Nas 1996, Mirasgedis et al. 2004).

5.1.1 Stages of CEA

Borrowed from (Mirasgedis et al. 2004), the CEA process encompasses the following four general methodological stages:

- **First Stage:** *Environmental Analysis: Technological data about each project and evaluation assumptions*. This step comprises the research and analysis of environmental specifications of older stock and the new proposed stock or additions, including data such as efficiency ratios, energy savings, reduction of GHG emissions, capacity, energy sources, installation requirements, time of replacement, etc. Assumptions about the evaluation period and a discount rate are made in order to reduce the various cost and benefit elements to a common base (Mirasgedis et al. 2004).

- **Second Stage:** *Economic Analysis: Project costs and benefits.* The economic analysis requires finding all the direct costs and benefits that will be involved during the adoption of each particular project in order to produce financial data results, and use this data in the next step. Included in the expenditures are the initial investment and installation costs, maintenance and operation, disposal of older stock, etc. Benefits include the savings from the adoption of each measure, potential revenues, etc.

- **Third Stage:** *Calculation of the net present value*. CEA involves a comparison of financial cost flows and CO_2e emission reductions occurring at different points in time, which has a significant impact on the results of the analysis (Mirasgedis et al. 2004). Cost flows are compared through the net present value (NPV):

$$\mathrm{NPV} = \sum_{t=0}^{T} \frac{C_t}{(1+r)^t}$$

Equation (1)

"where r is the discount rate, C_t is the net cost at time t and T is the evaluation period of the project. The CO_2e emission reductions occur at different points in time, in the same way as costs" (Mirasgedis et al. 2004). As an assumption to the model and to maintain consistency, "the CO_2e emission reductions are discounted with the same discount rate as the one used in Eq. (1), and thus, the net present value of emissions reduction (NPVE) is calculated as

Equation (2)
$$\mathrm{NPVE} = \sum_{t=0}^{T} \frac{E_t}{(1+r)^t}$$

where *Et* is the CO_2e emission reductions at time *t*” (Mirasgedis et al. 2004).

- **Fourth Stage:** *Evaluation indicators*. There are several different indicators available for the evaluation of financial results, including the internal rate of return (IRR), the benefit/cost ratio (B/C), net present value (NPV), and annuities or levelised costs. The internal rate of return provides a percentage rate from a given investment when the net present value is equated to zero. The benefit-cost ratio gives an easy indicator to read and rank projects. “Both the IRR and B/C indicators are neutral to the scale of costs, as well as to the CO_2e emission reductions achieved by the project” (Mirasgedis et al. 2004). The net present value takes into account the scale of the benefits and the costs, and can likewise be applied to the GHG emissions. However, to produce results that prove useful for comparison and ranking within a common time frame, a figure that takes into account both the economic results and the CO_2e emission reductions is needed. Thus a levelised cost per unit of CO_2e emission reduction proves useful in this study. The levelised cost can be defined as the monetary cost unit required to reduce one unit of GHG emissions. This criterion allows “the annual costs as well as CO_2e emission reductions to be transformed to constant annual flows over the lifetime of the investment” (Mirasgedis et al. 2004). The calculation of the total levelised cost (C_0) portion of a project can be solved using the following equation:

Equation (3)
$$C_0 = \mathrm{NPV} \cdot \frac{r}{1-(1+r)^{-t}}$$

And likewise for the levelised GHG emission reduction (E_0):

Equation (4)
$$E_0 = \mathrm{NPVE} \cdot \frac{r}{1-(1+r)^{-t}}$$

In order to combine and compare the results in one figure, the levelised cost per unit of CO_2e emission reduction of a specific project is estimated by dividing the C_0 with E_0 (Mirasgedis et al. 2004). The ranking can be performed by selecting the lowest levelised cost of a project (preferred) to the highest levelised cost in order to reduce one unit of CO_2e. “The use of levelised figures presents the following advantages compared to other evaluation criteria: (i) it gives a clear view of the scale of costs associated with the interventions under consideration; (ii) it establishes a consistent way to compare alternative mitigation options, which achieve different CO_2e emission reductions” (Mirasgedis et al. 2004).

5.2 Behavioural Positional Variables

As previously mentioned in multiple occasions, economic analysis largely determines investment decisions; nevertheless, attitudes and behaviour influence the adoption of such investments in less obvious ways. Three key positional variables that affect investment decision making, adopted from an earlier behavioural study by McKenzie-Mohr (1994), are incorporated into the assumptions of each of the 11 conservation projects and discussed in the results of the analysis.

- ***Disposable income*** has a pervasive effect in adopting measures that increase energy efficiency or add capacity, as the costs involved can be substantial. The larger the amount of disposable income, the higher the chances for investment.
- ***Home ownership*** Those who rent tend to be less well off and are therefore less disposed to make investments in efficiency; further, there is little incentive to make an investment in someone else's property (McKenzie-Mohr 1994). Efficiency investments with a quick payback, low initial cost, and that are transportable are more likely to be adopted by renters and the less wealthy (McKenzie-Mohr 1994). Examples include CFLs or a low flow shower head.
- ***Home repair skills*** affect the likelihood of conservation measures being undertaken. "The presence of someone with these skills both reduces the installation and maintenance costs of conservation devices and renders such devices more comprehensible" (McKenzie-Mohr 1994). For example, insulating a house requires a predisposition towards handy work.

An example of the aforementioned position variables at play is where "a householder may favourably evaluate a particular conservation measure, be compelled to take action to avoid losing further money, be committed to taking action, but nonetheless fail to act due to the fact that she is renting" (McKenzie-Mohr 1994). This example can help realize the importance of behavioural effects in decision making. Once a decision maker has taken action on a conservation project and realized the economic and environmental benefits stemmed from the investment, "[he or] she is likely to be ready to adopt other conservation measures as well as advocate conservation to others…A householder who has completed a retrofit is the most effective vehicle for reaching other households" (McKenzie-Mohr 1994).

5.3 Abatement Projects

Eleven conservation projects are individually appraised using environmental and economic criteria, and ranked in such a way that they maximize positive environmental impact and minimize costs of implementation (Mirasgedis et al. 2004). Admittedly, it is rather difficult to assess which conservation projects deserve more priority than others based on their visible impact. This decision making process should not depend on whether those benefits are visible or not. To illustrate, in a particular household, the effort that takes to change the behaviour of shutting the lights off after oneself for an entire month may be offset by turning the oven a few times more than normal (NRC 2008). The following section provides the main assumptions used in this study.

5.3.1 Assumptions about GHG Abatement Projects

As explained in the first two stages of the CEA model, certain assumptions of each conservation project must be made in order to proceed with data calculations. Behavioural considerations from sections 4.3.3. and 5.2 are also included here.

Replacement of heating equipment (M1)

- It is an investment in energy efficiency
- In 2007, 55.2% of heating equipment used natural gas as the energy source, and 20.3% used electricity
- 14.3% of natural gas equipment fell under low or standard efficiency (62% efficient). 13.9% of the stock are high efficiency (90% efficient or more)
- New equipment is estimated to last 20 years as long as it is properly maintained
- The decision to invest is highly influenced by economic analysis, disposable income, home ownership, and home repair skills

Replacement of windows and doors (M2)

- It is and investment in energy efficiency
- The majority of windows in Canadian homes are 16 years or older
- 37% of Canadian households reported to have drafts or leaks around windows in 2007
- Replacing windows and external doors with ENERGY STAR qualified products will typically save
- 7 % in heating energy use. The U-factor: <0.35.
- Window manufacturers offer 10 to 15 years of warranty. However, the new equipment is estimated to last 20 years
- The decision to invest is highly influenced by economic analysis, disposable income, home ownership, and home repair skills

Caulking and Weather stripping (M3)

- It is an investment in energy efficiency
- The majority of windows in Canadian homes are 16 years or older
- 37% of Canadian households reported to have drafts or leaks around windows in 2007
- Caulking and weather stripping can reduce 50% of air leakage.
- Weather stripping is estimated to last 5 years
- The decision to invest effort and money is highly influenced by home ownership and home repair skills

Insulation around hot water pipes (M4)

- It is an investment in energy efficiency
- About 50% of Canadian households reported that their property's hot water pipes were not insulated
- Savings are measured per meter of insulation for standard 22mm pipes, being effectively in use for 6 hours a day, and an average 5 meters of insulation per applicable household are used in the calculations
- Ambient temperature at 15 degrees, and pipe temperature at 70 degrees
- The new equipment is estimated to last 20 years
- The decision to invest effort and money is highly influenced by home ownership and home repair skills

Installation of a Programmable thermostat (M5)

- It is an investment in energy efficiency
- 52% of Canadians have not adopted this technology
- Manufacturers claim up to 30% reductions in energy consumption for space heating when properly programmed, achieved by lowering the normal temperature by a few degrees. A 15% conservative measure is employed in this analysis
- This equipment is estimated to last min. 10 years
- The decision to invest is highly influenced by disposable income, home ownership, home repair skills, management and curtailment

Installation of a solar water heater (M6)

- It is an investment in energy capacity
- For Canada’s climate characteristics, evacuated tube solar collectors seem to work best. These systems can reduce annual water heating costs by 40 to 50% in Canada, or higher % in sunnier, warmer areas
- For new buildings and refinancing, the system can readily become financially neutral or even profitable (i.e. negative costs)
- A conservative 60% of housing (apartments are not included in the analysis), or 45% of all Canadian housing is used as potential target for implementation of solar water heaters
- Some systems allow for hybrid uses, such as space or pool heating
- New equipment is estimated to last 20 years with little to no maintenance required
- The decision to invest is highly influenced by sound economic analysis and disposable income, home ownership, and home repair skills. It also involves management and curtailment at lesser degrees

Heater blanket on water heater (M7)

- It is an investment in energy efficiency
- A reduction of 4 to 9% in water heating costs is expected from adoption on normal stock heaters
- 63% of households in Canada use conventional heater tanks as their main source of hot water
- The new equipment is estimated to last 10 years
- The decision to invest is influenced by home ownership and home repair skills

Replacement of toilet with dual flush system (M8)

- It is an investment in natural resources conservation and energy efficiency
- The number of dual flush systems are conservatively estimated as the number of home owners (excludes renters), at one toilet per property; about 71% of total number of households
- Toilet flushing is the single largest end use of water, 30% of the daily water consumption
- A representative home of 2.6 bathrooms in Canada can reduce 56% of water used for toilet flushing by adopting this measure
- New equipment is estimated to last 20 years. Payback is estimated at 5.6 years
- The decision to invest is highly influenced by home ownership and home repair skills, and in less degree on disposable income

Installation of Low flow showerheads (M9)

- It is an investment in natural resources conservation and energy efficiency
- Based on average 5 minute shower per person per day. Longer showers are common
- Based on replacing stock 5 gallons per minute to 2.2 gallons per minute
- New equipment is estimated to last 10 years
- The decision to invest is influenced by home ownership

Compact fluorescent lamp CFL (M10)

- It is an investment in energy efficiency
- The average number of light bulbs per household in Canada is 24.2, out of which 65% (15.7 bulbs) are either incandescent or halogen. This represents the potential for CFL replacement.
- 3 CFLs, or 20% of potential replacement bulbs are used in the calculations
- Savings are calculated per bulb, being used for 5 hours per day, or 1825 hours per year
- The new equipment is estimated to last 10000 hours or 5.5 years
- The decision to invest is influenced by disposable income and home ownership

Indoor clothes drying (M11)

- Energy conservation behaviour both under curtailment and management
- The average basement or living space has enough heat to fully dry clothes in 5 to 8 hours.
- Time is a key factor in the adoption of this behavioural change. It requires planning and increased time spent for the activity. Less available time will hinder results, for example working parents
- The stock of dryers in Canada in 2007 was 10,973,469
- This measure requires that drying equipment be used only under necessary or discretionary circumstances, with an estimated 20% of use allocated to them.

6. ANALYSES & RESULTS

Environmental Analysis (Stage 1 CEA)

Economic Analysis (Stages 2, 3, 4 CEA)

Chapter 6 presents the environmental analysis, which is the first stage of CEA. After the calculation of energy savings and applicable CO_2 reduction, the economic analysis including stages 3 and 4 is discussed. In addition, the two research questions are answered.

6 Analyses & Results

To arrive to a useful interpretation of the CEA results using the levelised cost per unit of CO_2e emission reduction, first I present the findings from the first stage of CEA where the potential abatement for each conservation project is calculated. The economic evaluation follows. As previously explained in Chapter 2, Methodology, behavioural considerations are embedded throughout these analyses and in the results.

6.1 Environmental Analysis (Stage 1 CEA)

In order to calculate the potential GHG abatement for each project, and for the whole of the residential sector in Canada, the technically feasible CO_2e emission reduction must be calculated. Since the latest reliable data found from the different statistics sources in Canada at the time of study are from 2007, most figures are based in that year.

6.1.1 Technically Feasible CO_2e Emissions Reduction

The annual energy consumption of new stock and its corresponding rate of efficiency gain against the existing stock are summarized in Table 6.1. The resulting benefits of installing new stock are compared at the margin to calculate the energy savings and thus arrive to the average applicable CO^2e emissions reduction as it can be observed in Table 6.1. This data is estimated using the assumptions presented in section 5.3.1 above. The estimated penetration housing stock (see Appendix 6) is also summarized in Table 6.1.

All this information is necessary in order to calculate the technically feasible CO_2e emission reduction for each abatement project. This calculation is done by multiplying the calculated penetration housing stock by the calculated average applicable CO_2e reduction. The results of this calculation are presented in Table 6.2 for each of the household categories, and summarized in Figure 6.1.

Emission Abatement Project	Consumption new stock (kw/h)	Rate efficiency gain (%)	Energy savings (kw/h)	Penetration housing stock	Applicable CO_2e reduction (t CO_2e)
M1: Heating equipment	13653.72	0.30	5851.60	1,849,326	-1.230
M2: Windows	18139.95	0.07	1365.37	4,784,970	-0.287
M3: Weather stripping	18822.63	0.04	682.69	4,784,970	-0.144
M4: Insulation of hot water pipes	121.50	0.75	360.30	6,442,779	-0.076
M5: Programmable thermostat	16579.52	0.15	2925.80	6,687,513	-0.615
M6: Solar water heater	3323.73	0.40	2215.82	5,822,066	-0.466
M7: Heater blanket on water heater	5317.96	0.04	221.59	8,198,276	-0.047
M8: Dual flush system	271.99	0.56	346.16	9,249,014	-0.073
M9: Low flow showerhead	468.90	0.65	870.81	4,091,665	-0.183
M10: Replacement of CFL (3/household)	71.18	0.78	257.33	12,932,350	-0.054
M11: Clothes drying	200.00	0.79	739.00	10,973,469	-0.155

Table 6.1 Annual Consumption of New Stock (kw/h), Rate Efficiency Gain, Annual Energy Savings (kw/h), Estimated Penetration Rates, and Applicable Average CO_2e Emissions Reduction per Unit (t CO_2e)

Conservation measure	M1	M2	M3	M4	M5	M6	M7	M8	M9	M10	M11
Single Detached	**-1,316,922**	**-795,065**	**-397,535**	**-282,494**	**- 2,381,120**	**- 2,092,354**	**-221,075**	**-389,623**	**-433,607**	**- 1,213,498**	**-986,872**
Before 1969	-500,430	-302,125	-151,063	-107,348	-904,826	-795,095	-84,008	-148,057	-164,770	-461,129	-375,011
1970-1989	-500,430	-302,125	-151,063	-107,348	-904,826	-795,095	-84,008	-148,057	-164,770	-461,129	-375,011
1990-2007	-316,061	-190,816	-95,408	-67,799	-571,469	-502,165	-53,058	-93,510	-104,066	-291,239	-236,849
Double / Attached	**-359,799**	**-217,221**	**-108,611**	**-77,181**	**-650,550**	**-571,656**	**-60,400**	**-106,450**	**-118,466**	**-331,542**	**-269,625**
Before 1969	-136,723	-82,544	-41,272	-29,329	-247,209	-217,229	-22,952	-40,451	-45,017	-125,986	-102,457
1970-1989	-136,723	-82,544	-41,272	-29,329	-247,209	-217,229	-22,952	-40,451	-45,017	-125,986	-102,457
1990-2007	-86,352	-52,133	-26,067	-18,523	-156,132	-137,197	-14,496	-25,548	-28,432	-79,570	-64,710
Apartments	**-568,041**	**-342,943**	**-171,473**	**-121,851**	**- 1,027,072**	**n/a**	**-95,358**	**-168,060**	**-187,032**	**-523,430**	**-425,677**
Before 1969	-215,856	-130,318	-65,160	-46,303	-390,287	**n/a**	-36,236	-63,863	-71,072	-198,903	-161,757
1970-1989	-215,856	-130,318	-65,160	-46,303	-390,287	**n/a**	-36,236	-63,863	-71,072	-198,903	-161,757
1990-2007	-136,330	-82,306	-41,153	-29,244	-246,497	**n/a**	-22,886	-40,334	-44,888	-125,623	-102,163
Mobile Homes	**-30,345**	**-18,320**	**-9,160**	**-6,509**	**-54,866**	**-48,212**	**-5,094**	**-8,978**	**-9,991**	**-27,962**	**-22,740**
Before 1969	-11,531	-6,962	-3,481	-2,474	-20,849	-18,321	-1,936	-3,412	-3,797	-10,625	-8,641
1970-1989	-11,531	-6,962	-3,481	-2,474	-20,849	-18,321	-1,936	-3,412	-3,797	-10,625	-8,641
1990-2007	-7,283	-4,397	-2,198	-1,562	-13,168	-11,571	-1,223	-2,155	-2,398	-6,711	-5,458
Total in Canada	**-2,275,107**	**1,373,549**	**-686,778**	**-488,036**	**4,113,608**	**2,712,223**	**-381,927**	**-673,110**	**-749,096**	**2,096,431**	**1,704,913**
Grand Total for Canada	**-17,254,779**										

Table 6.2 Potential of CO_2e Emissions Reduction in Residential Buildings for 2007 (t CO_2e)

One of the main indicators used by individual consumers is the rate of efficiency gain (summarized in Table 6.1 above), which indicates the consumption of new stock over the old stock per measure. For example, the replacement of the heating equipment in this study is 30% more efficient than the current stock. While some projects may have a relatively insignificant change over the current stock, some others display improvements of as much as 79%. What consumers do not consider sometimes however, is the scale of the change. For example, insulating the hot water pipes (M4) which has a 75% efficiency gain may seem as more attractive compared to installing a programmable thermostat (M5) which shows a 15%. Nevertheless, the latter represents an impact of over eight times larger. So the scale of the changes, measured by the energy savings per project, can dictate which factor is more attractive. Energy savings ultimately translate into applicable emission reductions.

According to the calculated potential CO_2e emission reduction in the residential sector in Canada (Table 6.2 above), 17.2 Mt CO_2e can be reduced if all measures were adopted. These results are significant when we consider that most of the projects in this study are relatively simple to implement, and in most cases, also inexpensive. Figure 6.1 visually compares their calculated impact against one another.

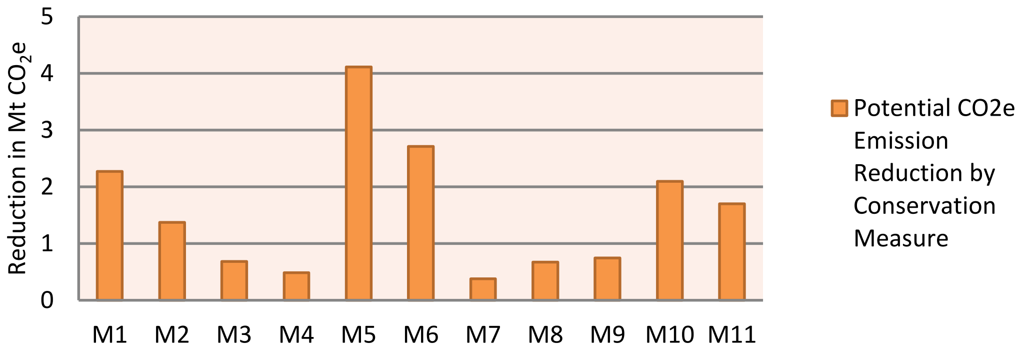


Figure 6.1: Potential CO_2e Emission Reduction by Conservation Measure (Mt CO_2e)

It is important to recognize that the implementation of all these measures at the same time may overestimate the results. For example, if all windows were replaced, the savings from caulking and weather stripping would virtually disappear. Likewise, the results from installing highly efficient furnaces are prone to slightly reducing the impact of using a programmable thermostat. Nevertheless, the figures in this study do not represent the total maximum emissions reduction potential due to a variety of reasons. First, the numbers were gathered from 2007 data, which are likely to be lower than current 2010-11 consumption patterns. Second, the assumptions presented in this study (5.3.1) are also purposely chosen on the conservative side of the potential savings 'spectrum'. Finally, there are multiple other related projects that will decreasingly conserve more energy if they were implemented.

With this in mind, the results show that the largest reduction potential lies in the space and water heating reducing projects (M1-M7), which are responsible for 70% of the estimated results. These are mainly one-time changes in behaviour and are regarded as investment, meaning that the levels of comfort remain unchanged. M10 (CFL replacement) remains a significant measure with 12% of the total potential impact, even by replacing a very conservative figure of 3 bulbs per household; M10 is also an investment in energy efficiency. M11 (Indoor clothes drying) on the other hand, although it has considerable reduction potential, relies almost entirely on curtailment and requires strong behavioural changes to the normal patterns.

The calculation of the NPVE and the levelised annual conservation flows (Eo) are summarized in Appendix 7.

6.2 Economic Analysis (Stages 2, 3, 4 CEA)

The economic analysis considers the direct financial costs and benefits, and these are in turn evaluated using cost effectiveness analysis (CEA). Almost all measures include an initial investment, and only M1 had operating and maintenance (O&M) costs. Stages 3 and 4 of CEA are also calculated in order to arrive to the main figure of the study: the levelised cost per unit of emission reduction, summarized in Figure 6.2. The results from the economic analysis are summarized in Table 6.3 below.

Conservation Project	Initial Invest-ment (CDN$)	Annual Savings (CDN$)	O&M (CDN$)	Net Cash flow (CDN$)	T (yr)	NPV ($CDN)	% Rate	Leveli-sed *Co* (CDN$)
M1: Heating equipment	$7000	$568	$100	$468	20	($1807)	6,4%	($163)
M2: Windows	$5000	$132	$0	$132	20	($3529)	6,4%	($318)
M3: Weather stripping	$250	$66	$0	$66	5	$26	6,4%	$6
M4: Insulation around hot water pipes	$17	$35	$0	$35	20	$371	6,4%	$33
M5: Programmable thermostad	$90	$284	$0	$284	10	$1960	6,4%	$271
M6: Solar water heater	$2500	$215	$0	$215	20	($113)	6,4%	($10)
M7: Heater blanket on water heater	$22	$21	$0	$21	10	$133	6,4%	$18
M8: Dual flush system	$363	$34	($65)	$98	20	$730	6,4%	$66
M9: Low flow showerhead	$12	$84	$0	$84	10	$598	6,4%	$83
M10: CFL (per 3 bulbs)	$12	$25	$0	$25	5,5	$101	6,4%	$22
M11: Indoors clothes drying	$0	$72	$0	$72	1	$67	6,4%	$72

Table 6.3 Economic Analysis of Conservation Projects

These results indicate that 3 of the 11 projects have a negative net present value at the end of their useful life, namely M1 (changing low efficient heating systems to high efficiency units), M2 (replacing windows with Energy Star equipment), and M6 (installing solar water heaters). Having a negative NPV, and therefore a levelised cost of reduction, doesn’t imply that the projects should be avoided (their implementation often bring about large environmental benefits), but rather implies that such projects are likely to be avoided by individual consumers. One reason for this is that the costs of adoption will need to be assimilated by the user, while the environmental benefits are in turn shared by the community. It may require altruistic attitudes by the user in order to adopt such measures. Alternatively, government aid, in the form of grants for example, can help offset the excess cost and consequently increase the adoption rates of projects that include a private cost. Yet another option that may serve the same purpose is to have access to preferential financing options. People with excess disposable income are more likely to bear the costs of implementation under the assumptions of the behavioural positional variables (section 5.2).

In regards to the discount rate, a 6.4% figure was used as posted by the major banking entities in Canada for home-owner loans intended for retrofit projects and refinancing in the first trimester of 2010. In the case of preferential financing offers, which would effectively alter the discount rate, different results would be expected. In particular, only a 1% decrease in the interest rate is enough to make M6 an attractive option for investment. Grants or rebates should have a similar effect, meaning an increase in the adoption rates of conservation projects.

The arrival to the levelised costs allows for the comparison of projects using the same unit of measure; furthermore, this allows for the ranking of such projects. Scenario analysis during the study showed that several points lower in the interest rate or larger grants are necessary for M1 and M2 to become financially attractive on average (each dwelling's characteristics may dictate otherwise). The resulting levelised costs from the study with a 2% lower interest rate scenario analysis are shown in Figure 6.2 below.

	M1	M2	M3	M4	M5	M6	M7	M8	M9	M10	M11
6.4 % Standard	(132)	(1107)	43	441	441	(22)	396	903	452	412	461
4.4 % Reduced	(54)	(866)	66	444	443	52	402	972	453	415	461

Figure 6.2: Levelised Cost per Ton of CO_2e Emission Abatement

The positive numbers (the top of the graph) in Figure 6.2 represent net economic benefits, and the negative numbers (bottom of the graph) represent costs per unit of reduction. Figure 6.2 and what follows are the answer for the first research question:

Q1: ***Based on the CEA, what is the cost of being environmentally responsible within Canada's residential sector regarding the selected emission abatement projects?***

All but three of the studied conservation projects not only have positive NPV under the assumptions of this study, but in many cases, the investment may prove to be lucrative (negative costs) to the individual consumer, albeit at small scales. For example, insulating the hot water pipes and installing a programmable thermostat, each have the potential to pay itself 21 times over their useful lifetime. Dual flush toilets will duplicate their initial investment, and in the rare exception of low flow showerheads, the investment is paid 48 times over.

The financial investment may prove to be beneficial, but equally or more importantly is to incorporate the scale of emission reduction that each project may provide. This is necessary to compare and rank each of the projects in accordance to the method presented. The levelised cost per unit of CO_2e emission reduction shown in Figure 6.2 reveal that eight conservation projects offer net economic benefits (negative costs) under the normal interest rate, and can potentially reduce 10.9 Mt of CO_2e. In other words, 63% of the total reductions identified in this study are achievable with net economic benefits. Under the lower interest rate scenario, M6 (installing a solar water heater) will also reflect net economic benefits, bumping to total to 13.6 Mt CO_2e or 79% of the reduction potential with net economic benefits to the consumer.

The remaining 27% of conservation potential could be attained at a cost under the normal scenario. The different scenario results showcase the strong tendency of the majority of the conservation projects to remain relatively unchanged, meaning that the adoption of most interventions are beneficial to the average consumer, even if they are not enhanced by government assistance. *"This fact indicates that a considerable number of energy consumers have limited information on energy conservation techniques, while at the same time, institutional arrangements for promoting clean energy and energy efficient technologies are weak"*(Mirasgedis, et al. 2004).

One can observe from Figure 6.2 that the conservation project that presents the largest benefits is M8, replacing standard toilets with dual flush systems. One way to interpret this result is as follows: *If a consumer (or entity) wants to reduce one ton of CO_2e in Canada, he or she can receive CDN$903 for investing in the replacement of dual flush toilets, during the life of the investment.* Indeed, this conservation measure not only saves enormous amounts of water per year, which translates into positive yearly cash flows from the water savings (see Table 6.3 above), but also prevents excess water from going into the water and sewage treatment plants. The sewage treatment costs accounts for the majority of the water bill; water treatment requires energy to treat it and pump it back out into the system. The high penetration rates are another reason that the benefits from this investment are particularly large in Canada. This may not be the case in some countries such as Sweden or Germany, where dual flush toilets are the standard.

Following with the ranking of projects, the following six conservation projects (M4, M5, M7, M9, M10, M11) yield similar benefits among them per ton of CO_2e reduced, in the range of \$396 to \$461. M4 and M5 have virtually the same net economic benefit of \$441/t CO_2e reduced, yet as mentioned earlier, insulating a dwellings' hot water pipes may reduce 8 times less CO_2e than a properly programmed thermostat. Nevertheless, M4 costs significantly less, so they are comparable at the margin of emissions reduction. These projects are followed by M3, M6, M1, and M2 as the most costly to implement. Projects that result in net economic benefits should be prioritized.

Thus, the results from this study reveal the following:

- *Interventions related to space heating.* The projects related to this category are M1, M2, M3, and M5, and together they account for nearly half (49%) of the potential emission reductions. Nevertheless, their economic performance is hindered by economic costs in M1 and M2. Government interventions, particularly in furnace replacement (M1) could increase the rate of adoption of this measure by providing grants that reduce the financial burden of buying the new equipment, thus increasing the effectiveness of this category. M2 results in the highest costs per unit of emission abatement on average; therefore, it is placed at the bottom of the list.
- *Interventions related to water heating and water conservation.* These projects (M4, M6, M7, M8, and M9) present a considerable emissions reduction potential, 29% in total. All measures except M6 present net economic benefits. Nevertheless, M6 (solar water heating) requires only a minor cost per ton of CO_2e reduction which could be offset by a lower interest rate or grants that help reduce the initial investment cost. Once this hurdle is overcome, installing solar water heaters have tremendous potential for emissions abatement in Canada, and should be carefully considered and supported by decision makers.
- *Interventions related to lighting and energy conservation.* Replacing incandescent and halogen light bulbs with CFL´s (M10) are still a significant energy and emission reduction measure, even after nearly 30 years of promotion in Canada. This investment shows great benefits, easy adoption, and no change in the level of comfort. On the contrary, indoor clothes drying (M11) requires profound changes in attitudes and behaviour in order to achieve the targets stipulated in this study. It is entirely considered as curtailment, as drying machines are available but are not being fully utilized. This is comparable to walking or biking while having a car in the garage. Nevertheless, they both represent noteworthy reductions, in the order of 22% of the total reductions identified.

Granted that the financial results from this research are accurate, the numbers beg the question of why adoption patterns are not much higher. Rephrasing the previous question leads to the second research question:

Q2: ***Based on the CEA, from a behavioural perspective, what are some of the reasons of the current adoption rates of the Canadian residential sector regarding the selected emission abatement projects?***

One argument of this controversial behaviour relates to disinformation, and/or the lack of proper information. To illustrate, householders grossly overestimate the resources used by visible devices such as lighting and greatly underestimate less visible resource consumption such as water heaters and furnaces (McKenzie-Mohr 1994). *"This void of information has been compared to going grocery shopping and discovering that none of the items that you wish to purchase have prices. All that you receive when you go through the checkout is a total for the items purchased. You are left on your own to estimate the cost of each item"* (McKenzie-Mohr 1994). The contrary is also true that during the last few decades, an exponentially growing influx of information about energy savings became available to consumers. This bombardment of information faced by consumers when doing research plays a role in actually deterring or delaying consumer's action, as one seeks out for "the best" option. Marketing campaigns by companies provide much of this information influx, which has the potential of being biased.

Once (and if) consumers or private entities receive proper information and are able to compare conservation measures, they now face the up-front costs of implementation. This is an equally challenging factor that deters much of the environmental investments. The reason lies in that the benefits are spread throughout the life of the investment, but the manufacturers or service suppliers often demand full payment. This leaves the householder with the problem of finding the financing options on his own. Once again, government and/or private entities need to provide means that encourage adoption, in particular the financing of these up-front costs which can be substantial for the average consumer.

Yet, perhaps the biggest factors responsible for the low rates of adoption of conservation measures are the failure of linking the economic analysis to their corresponding environmental benefits, and the lack of recognition of behavioural considerations. Consumers often only explore the economic portion of the analysis, which constitutes the basis of their decision making. If investment decisions show signs of costs instead of benefits, adoption is discouraged and the projects are discarded or postponed. Evidence of this can be seen in the paramount emphasis placed upon the 'recovery of the investment'. This has become ***the*** defining factor for most of the conservation projects offered. If the investment can be recovered, then it is adopted; otherwise it is discarded. Therefore, a disconnect from the corresponding environmental benefits is often found; those conservation projects are sent to the back seat. Similar effects occur when a decision maker is not aware of the behaviour factors that affect the decision making process, as explained throughout this paper and other studies in the behavioural field.

When a consumer has received proper information and has the financial means, *'then'* is when attitude and behaviour considerations kick in. Once a consumer understands and decides to adopt a particular conservation measure, and he or she is able to finance this decision, it is attitudes and behaviour towards environmental conservation that will ultimately determine positive action, or the lack of. Analytical frameworks that allow for the incorporation of different variables that affect decision making, such as environmental performance and attitudes and behaviour, may speed up the process of adopting technologies that reduce emissions, as well as adopting reduction behaviours to bring our excess-driven consumption patterns to more sustainable levels.

7 Conclusion

The conservation measures selected for this study target head-on the more energy intensive sub-sectors of residential energy consumption (space and water heating), contributing to relatively large potential GHG emission reductions, and in most cases, at low levels of investment. The implementations of these measures could help reduce 17.2 Mt CO_2e emissions while maintaining equivalent levels of comfort. CEA within the context of this study demonstrated that 10.9 Mt CO_2e can be reduced with net economic benefits and no government intervention.

As the majority of households fall into the single detached category, the great majority being 20 years old or more, and with high levels of consumption, it makes the residential sector in Canada an attractive segment for mass implementation of emission abatement projects, starting with those that present net economic benefits per ton of CO_2e reduction and moving into interventions that require low or moderate social assistance, such as government grants or preferential financing options. This provides an incremental path to engaging into further retrofits that require more knowledge, resources, or financing for successful adoption.

Currently in Canada, energy consumers are neither pressured by natural scarcity nor strict policies aimed for the adoption of conservation measures. Government emission abatement programs tailored to the residential sector are available for voluntary adoption, and in some cases they expire unused. At the same time, due to abundant resources, economic conditions, and lifestyles, energy and resource prices in Canada remain relatively low, making changes in attitudes and behaviour harder to implement. The Canadian government and/or private entities need to disseminate tested information about conservation measures that account for both the economic and the environmental performances, enabling unbiased comparison. One of the reasons that I point at governments is because this study does not include the social costs associated with cleaning up environmental degradation, which is by itself a market failure. A cost benefit analysis (CBA) that includes both private and social costs will unequivocally improve the results of this study in favour of adopting conservation measures.

It would likely take sharp increases in energy prices, or a decrease of economic activity within a very short span to create change in a large scale, not only by investing in energy efficient measures, but to decrease the high levels of energy consumption per capita in Canada. Changes in consumer education programs and the current approach to adopting reduction measures should not be focused or limited to the recovery of the investment, but rather on the realization of the benefits (necessarily both economic and environmental) that follow as a result of the investment. That way, energy consumers are likely to be ready to adopt other progressively more challenging conservation projects, as well as to advocate conservation practices to others (McKenzie-Mohr 1994). These progressive changes in attitudes and behaviour towards energy conservation or even energy reduction have an even larger potential if they begin to spread out to other sectors of the economy, such as transportation, which consumes nearly twice the amount of non-renewable resources than the residential sector. As an ultimate goal, it is changes in the attitudes towards curtailment practices that will generate the largest reductions of harmful gases due to our current economic activity and consumer-driven lifestyles.

References

Arbnor, I & Bjerke B 1997, *Methodology for creating business knowledge*, 2nd edn., Sage Publications, California.

Arbnor, I & Bjerke B 2009, *Methodology for creating business knowledge*, 3rd edn., Sage Publications, California.

Aydinalp, M, Ugursal, VI, Fung, AS 2001, 'Modelling of the appliance, lighting, and space-cooling energy consumptions in the residential sector using neural networks', *Applied Energy*, vol. 71, no. 2, February 2002, pp. 87-110, viewed 20 September 2011, http://www.sciencedirect.com/science/article/pii/S0306261901000496.

Brandon, G & Lewis, A 1999, 'Reducing household energy consumption: A qualitative and quantitative field study', *Journal of Environmental Psychology*, vol. 19, no. 1, March 1999, pp. 75-85, viewed 17 September 2011, http://www.sciencedirect.com/science/article/pii/S0272494498901050.

Capitalism: A Love Story 2009, documentary, Overture Films and Paramount Vantage, USA.

Central Intelligence Agency (CIA) 2011, *The World Factbook. Canada*, viewed 17 September 2011, https://www.cia.gov/library/publications/the-world-factbook/geos/ca.html.

Consumer Energy Alliance (CEA) 2011, *Home Use*, p. 1, viewed 24 March 2010, http://consumerenergyalliance.org/howisenergyused/home-use/.

GHG Protocol 2004, *The GHG Protocol.Corporate Accounting and Reporting Standard, Revised Edition*, viewed 24 March 2010, http://www.ghgprotocol.org/files/ghgp/public/ghg-protocol-revised.pdf.

Home 2009, documentary, Europa Corp, France.

Hubbard, G 2006, 'Measuring Organizational Performance: Beyond the Triple Bottom Line', *Business Strategy and the Environment*, vol. 18, no. 3, March 2009, pp. 177-191, viewed 20 September 2011, viewed 3 March 2011, http://onlinelibrary.wiley.com/doi/10.1002/bse.564/pdf.

International Energy Agency (IEA) 2010, *CO_2 Emissions from Fuel Combustion*, 2010 Edition, viewed 24 March 2010, http://www.t.org/co2highlights/co2highlights.pdf.

Jaccard, M, Loulou, R, Kanudia, A, Nyboer, J, Bailie, A, Labriet, M 2003, 'Methodological contrasts in costing greenhouse gas abatement policies: Optimization and simulation modeling of micro-economic effects in Canada', *European Journal of Operational Research*, vol. 145, no. 1, 16 February 2003, pp. 148-164, viewed 20 September 2011, http://www.sciencedirect.com/science/article/pii/S0377221701004027.

Jackson, T 2009, *Prosperity without growth. Economics for a finite planet*. Earthscan, London, UK.

Leonard-Barton, D 1981, ’Voluntary Simplicity Lifestyles and Energy Conservation’, J*ournal of Consumer Research,* vol. 8, no. 3, December 1981, pp. 243-252, viewed 23 March 2010, http://www.sfu.ca/cmns/faculty/marontate_j/801/08-spring/readings/Leonard-Barton_VoluntarySimplicityLifestylesEnergyConservation.pdf.

McKenzie-Mohr, D 1994, ‘Social Marketing for Sustainability: The case of residential energy conservation, *Futures*, vol. 26, no. 2, March 1994, pp.224-233, viewed 20 March 2010, www.sciencedirect.com/science/article/pii/0016328794901112.

Mirasgedis, S, Georgopoulou, E, Sarafidis, Y, Balaras, C, Gaglia, A, Lalas, DP 2004, ‘CO_2 emission reduction policies in the Greek residential sector: a methodological framework for their economic evaluation’ *Energy Conversion and Management*, vol. 45, no. 4, March 2004, pp.537-557, viewed 10 August 2009, http://www.sciencedirect.com/science/article/pii/S0196890403001602.

Nas, TF 1996, *Cost Benefit Analysis: Theory and Application*, *Sage Publications,* California.

National Energy Board (NEB) 2009, *Attitude and Behaviour Shaping Energy Use. Energy Demand*. November 2009, viewed 20 March 2010, http://www.neb.gc.ca/clf-nsi/rnrgynfmtn/nrgyrprt/nrgdmnd/tttdbhvrshpngnrgs2009/tttdbhvrshpngnrgs-eng.pdf.

National Energy Board (NEB) 2009a, *Canadian Energy Overview 2008*, viewed 19 September 2011, http://www.neb.gc.ca/clf-nsi/rnrgynfmtn/nrgyrprt/nrgyvrvw/cndnnrgyvrvw2008/cndnnrgyvrvw2008-eng.pdf.

National Geographic 2011, ’Consumption’, *National Geographic*, January 2011, viewed 15 September 2011, p. 42.

Natural Resources Canada (NRC) 2006, *Improving Energy Performance in Canada. Report to Parliament Under the Energy Efficiency Act For the Fiscal Year 2005-2006*, viewed 11 October 2010, http://oee.nrcan-rncan.gc.ca/Publications/statistics/parliament05-06/pdf/parliament05-06.pdf.

Natural Resources Canada (NRC) 2007, *2007 Survey of Household Energy Use (SHEU-2007)*, viewed 11 October 2010, http://oee.nrcan.gc.ca/corporate/statistics/neud/dpa/data_e/sheu07/tables.cfm?attr=0.

Natural Resources Canada (NRC) 2008, *Energy Efficiency Trends in Canada 1990-2005*, viewed 24 November 2010, http://oee.nrcanrncan.gc.ca/Publications/statistics/trends07/chapter3.cfm?attr=0.

Natural Resources Canada (NRC) 2009, *Comprehensive Energy Use Database, Residential Sector, 1990-2008,* viewed 18 August 2010, http://oee.nrcan.gc.ca/corporate/statistics/neud/dpa/comprehensive_tables/index.cfm?fuseaction=Selector.showTree.

Natural Resources Canada (NRC) 2009, *Energy Efficiency Trends in Canada. 1990 – 2007*, viewed 24 November 2010, http://www.oee.nrcan.gc.ca/Publications/statistics/trends09/pdf/trends.pdf.

Planeten 2006, documentary, Charon & SVT Sweden.

Saidur, R, Masjuki, HH, Jamaluddin, MY, Ahmed, S 2007, Energy and associated greenhouse gas emissions from household appliances in Malaysia, *Energy Policy*, vol. 35, no. 3, March 2007, pp. 1648-1657, viewed 20 September 2011, http://www.sciencedirect.com/science/article/pii/S0301421506002047.

Sviokla, J 2008, 'Want to Reduce Your Energy Use? Measure it', *Harvard Business Review*, 6 August 2008, viewed 19 September 2011, http://blogs.hbr.org/sviokla/2008/08/post.html#.TnoL-GdSno4.email.

Steg, L 2008, 'Promoting household energy conservation', Energy Policy, vol. 36, no. 12, December 2008, pp. 4449-4453, viewed 21 September 2011, http://www.sciencedirect.com/science/article/pii/S0301421508004643.

Swan, LG & Ugursal, VI 2009, 'Modelling the end-use energy consumption in the residential sector: A review of modelling techniques', *Renewable and Sustainable Energy Reviews*, vol. 13, no. 8, October 2009, pp. 1819-1835, viewed 17 September 2011, http://www.sciencedirect.com/science/article/pii/S1364032108001949.

Swedish Energy Agency (SEA) 2010, *Energy in Sweden 2010*, viewed 15 January 2010, http://webbshop.cm.se/System/ViewResource.aspx?p=Energimyndigheten&rl=default:/Resources/Permanent/Static/b47b00212456b9bdbdbe47a009474/ET2010_47w.pdf.

The 11th Hour 2007, documentary, Warner Independent Pictures USA.

The Age of Stupid 2009, documentary, Spanner Films UK.

The Pew Charitable Trusts 2010, *Who's Winning the Clean Energy Race? Growth, Competition, and Opportunity in the World's Largest Economies*, viewed 24 March 2010, http://www.pewtrusts.org/uploadedFiles/wwwpewtrustsorg/Reports/Global_warming/G-20%20Report.pdf.

United Nations Framework Convention on Climate Change (UNFCCC) 2010, *Status of Ratification of the Kyoto Protocol*, viewed 4 May 2010, http://unfccc.int/kyoto_protocol/status_of_ratification/items/2613.php.

Van Houwelingen, J & Van Raaij, WD 1989, 'The effect of goal-setting and daily electronic feedback on in-home energy use', *Journal of Consumer Research*, vol. 16, June 1989, viewed 21 September 2011, http://www.comedamifuture.com/Resources/VanHouwelinger_Expectations_JCR.pdf.

Van Raaij, WD & Verhallen, TMM 1983, 'A behavioural model of residential energy use', *Journal of Economic Psychology*, vol. 3, no. 1, 1983, pp. 39-63, viewed 19 September 2011, http://www.sciencedirect.com/science/article/pii/0167487083900570

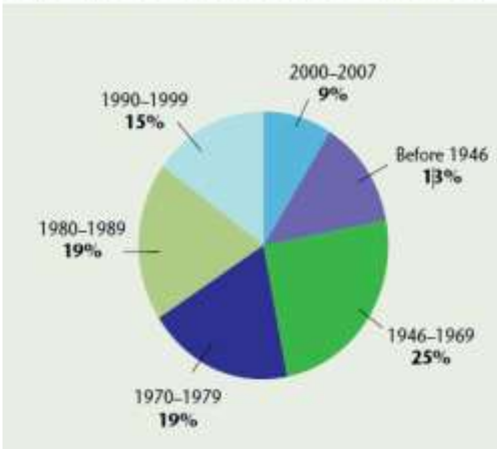
Appendix 1 Household Distribution

Building Distribution	# Households	%
Canada	12,932,350	
Single Detached	**7,485,759**	57.88%
Before 1969	2,844,588	22.00%
1970-1989	2,844,588	22.00%
1990-2007	1,796,582	13.89%
Double / Attached	**2,045,197**	15.81%
Before 1969	777,175	6.01%
1970-1989	777,175	6.01%
1990-2007	490,847	3.80%
Apartments	**3,228,906**	24.97%
Before 1969	1,226,984	9.49%
1970-1989	1,226,984	9.49%
1990-2007	774,937	5.99%
Mobile Homes	**172,488**	1.33%
Before 1969	65,545	0.51%
1970-1989	65,545	0.51%
1990-2007	41,397	0.32%

Source: NRC (2007)

Chart 6. Type of dwelling by year of construction, 2007

Chart 2. Year of construction of dwellings, 2007



Appendix 2 Residential Energy Consumption Composition

Building Distribution	# Households	Total Energy Consumption	Total GHG	Total Electricity	GHG Electricity	Natural Gas	Nat Gas GHG
Canada	**12,932,350**	**1,447.20**	**74.30**	**557.10**	**33.30**	**683.60**	**34.00**
Single Detached	**7,485,759**	**1,019.80**	**51.60**	**364.40**	**21.70**	**494.30**	**24.50**
Before 1969	2,844,588	378.20	19.14	132.56	7.89	171.54	8.50
1970-1989	2,844,588	382.38	19.35	140.99	8.40	179.78	8.91
1990-2007	1,796,582	259.22	13.12	90.84	5.41	142.97	7.09
Double / Attached	**2,045,197**	**138.80**	**7.30**	**54.70**	**3.30**	**70.10**	**3.50**
Before 1969	777,175	51.47	2.71	19.90	1.20	24.33	1.21
1970-1989	777,175	52.04	2.74	21.16	1.28	25.50	1.27
1990-2007	490,847	35.28	1.86	13.64	0.82	20.28	1.01
Apartments	**3,228,906**	**257.50**	**13.80**	**127.00**	**7.60**	**103.90**	**5.20**
Before 1969	1,226,984	95.50	5.12	46.20	2.76	36.06	1.80
1970-1989	1,226,984	96.55	5.17	49.14	2.94	37.79	1.89
1990-2007	774,937	65.45	3.51	31.66	1.89	30.05	1.50
Mobile Homes	**172,488**	**31.10**	**1.60**	**11.00**	**0.70**	**15.30**	**0.80**
Before 1969	65,545	11.53	0.59	4.00	0.25	5.31	0.28
1970-1989	65,545	11.66	0.60	4.26	0.27	5.56	0.29
1990-2007	41,397	7.91	0.41	2.74	0.17	4.43	0.23

Source: NRC (2007). Energy (Electricity and Natural Gas) in Petajoules. GHG expressed in Mt CO_2e

Appendix 3 Residential Space Heating Energy Use and GHG Emissions

Building Distribution	# Households	Electricity	GHG	Natural Gas	GHG	Heating Oil	GHG	Other	GHG	Wood	GHG
Canada	**12,932,350**	**228.90**	**13.60**	**489.50**	**24.30**	**75.50**	**5.30**	**14.60**	**0.90**	**99.60**	**0.00**
Single Detached	**7,485,759**	**171.03**	**10.02**	**365.74**	**17.91**	**56.41**	**3.91**	**10.91**	**0.66**	**74.42**	**0.00**
Before 1969	2,844,588	64.99	3.81	138.98	6.81	21.44	1.48	4.15	0.25	28.28	0.00
1970-1989	2,844,588	64.99	3.81	138.98	6.81	21.44	1.48	4.15	0.25	28.28	0.00
1990-2007	1,796,582	41.05	2.41	87.78	4.30	13.54	0.94	2.62	0.16	17.86	0.00
Double / Attached	**2,045,197**	**20.14**	**1.23**	**43.07**	**2.20**	**6.64**	**0.48**	**1.28**	**0.08**	**8.76**	**0.00**
Before 1969	777,175	7.65	0.47	16.37	0.84	2.52	0.18	0.49	0.03	3.33	0.00
1970-1989	777,175	7.65	0.47	16.37	0.84	2.52	0.18	0.49	0.03	3.33	0.00
1990-2007	490,847	4.83	0.30	10.34	0.53	1.59	0.12	0.31	0.02	2.10	0.00
Apartments	**3,228,906**	**32.49**	**2.07**	**69.48**	**3.69**	**10.72**	**0.81**	**2.07**	**0.14**	**14.14**	**0.00**
Before 1969	1,226,984	12.35	0.79	26.40	1.40	4.07	0.31	0.79	0.05	5.37	0.00
1970-1989	1,226,984	12.35	0.79	26.40	1.40	4.07	0.31	0.79	0.05	5.37	0.00
1990-2007	774,937	7.80	0.50	16.68	0.89	2.57	0.19	0.50	0.03	3.39	0.00
Mobile Homes	**172,488**	**5.24**	**0.31**	**11.21**	**0.55**	**1.73**	**0.12**	**0.33**	**0.02**	**2.28**	**0.00**
Before 1969	65,545	1.99	0.12	4.26	0.21	0.66	0.05	0.13	0.01	0.87	0.00
1970-1989	65,545	1.99	0.12	4.26	0.21	0.66	0.05	0.13	0.01	0.87	0.00
1990-2007	41,397	1.26	0.07	2.69	0.13	0.42	0.03	0.08	0.00	0.55	0.00

Source: NRC (2007). Energy (Electricity, Natural Gas, Heating Oil, Other, Wood) in Petajoules. GHG expressed in Mt CO_2e

Appendix 4 Residential Water Heating Energy Use and GHG Emissions

Building Distribution	# Households	Electricity	GHG	Natural Gas	GHG
Canada	**12,932,350**	**53.20**	**3.20**	**187.80**	**9.30**
Single Detached	**7,485,759**	**32.59**	**1.96**	**115.05**	**5.69**
Before 1969	2,844,588	12.39	0.74	43.72	2.16
1970-1989	2,844,588	12.39	0.74	43.72	2.16
1990-2007	1,796,582	7.82	0.47	27.61	1.37
Double / Attached	**2,045,197**	**5.94**	**0.36**	**20.97**	**1.04**
Before 1969	777,175	2.26	0.14	7.97	0.40
1970-1989	777,175	2.26	0.14	7.97	0.40
1990-2007	490,847	1.43	0.09	5.03	0.25
Apartments	**3,228,906**	**13.57**	**0.84**	**47.91**	**2.43**
Before 1969	1,226,984	5.16	0.32	18.21	0.92
1970-1989	1,226,984	5.16	0.32	18.21	0.92
1990-2007	774,937	3.26	0.20	11.50	0.58
Mobile Homes	**172,488**	**1.09**	**0.07**	**3.86**	**0.21**
Before 1969	65,545	0.42	0.03	1.47	0.08
1970-1989	65,545	0.42	0.03	1.47	0.08
1990-2007	41,397	0.26	0.02	0.93	0.05

Source: NRC (2007). Energy (Electricity and Natural Gas) in Petajoules. GHG expressed in Mt CO_2e

Appendix 5 Residential Appliance and Lighting Electricity Use and GHG Emissions

		Appliances		Lighting	
Building Distribution	**# Households**	**Electricity**	**GHG**	**Electricity**	**GHG**
Canada	**12,932,350**	**186.20**	**11.40**	**60.80**	**3.60**
Single Detached	**7,485,759**	**113.42**	**6.68**	**46.20**	**2.70**
Before 1969	2,844,588	43.10	2.54	17.56	1.03
1970-1989	2,844,588	43.10	2.54	17.56	1.03
1990-2007	1,796,582	27.22	1.60	11.09	0.65
Double / Attached	**2,045,197**	**19.16**	**1.16**	**6.00**	**0.40**
Before 1969	777,175	7.28	0.44	2.28	0.15
1970-1989	777,175	7.28	0.44	2.28	0.15
1990-2007	490,847	4.60	0.28	1.44	0.10
Apartments	**3,228,906**	**49.74**	**2.90**	**7.70**	**0.50**
Before 1969	1,226,984	18.90	1.10	2.93	0.19
1970-1989	1,226,984	18.90	1.10	2.93	0.19
1990-2007	774,937	11.94	0.70	1.85	0.12
Mobile Homes	**172,488**	**3.87**	**0.19**	**0.90**	**0.10**
Before 1969	65,545	1.47	0.07	0.34	0.04
1970-1989	65,545	1.47	0.07	0.34	0.04
1990-2007	41,397	0.93	0.05	0.22	0.02

Source: NRC (2007) Energy (Electricity) in Petajoules. GHG expressed in Mt CO_2e

Appendix 6 Calculation of Penetration Rates Per Conservation Project

	M1	M2	M3	M4	M5	M6	M7	M8	M9	M10	M11
Single Detached	**1,070,464**	**2,769,731**	**2,769,731**	**3,729,337**	**3,870,999**	**4,491,455**	**4,745,489**	**5,353,697**	**2,368,419**	**22,457,277**	**6,351,881**
Before 1969	406,776	1,052,498	1,052,498	1,417,148	1,470,980	1,706,753	1,803,286	2,034,405	899,999	8,533,765	2,413,715
1970-1989	406,776	1,052,498	1,052,498	1,417,148	1,470,980	1,706,753	1,803,286	2,034,405	899,999	8,533,765	2,413,715
1990-2007	256,911	664,735	664,735	895,041	929,040	1,077,949	1,138,917	1,284,887	568,420	5,389,746	1,524,451
Double / Attached	**292,463**	**756,723**	**756,723**	**1,018,898**	**1,057,602**	**1,227,118**	**1,296,523**	**1,462,693**	**647,080**	**6,135,591**	**1,735,408**
Before 1969	111,136	287,555	287,555	387,181	401,889	466,305	492,679	555,823	245,890	2,331,525	659,455
1970-1989	111,136	287,555	287,555	387,181	401,889	466,305	492,679	555,823	245,890	2,331,525	659,455
1990-2007	70,191	181,613	181,613	244,536	253,825	294,508	311,166	351,046	155,299	1,472,542	416,498
Apartments	**461,734**	**1,194,695**	**1,194,695**	**1,608,611**	**1,669,716**	n/a	**2,046,918**	**2,309,263**	**1,021,593**	**9,686,718**	**2,739,819**
Before 1969	175,459	453,984	453,984	611,272	634,492	n/a	777,829	877,520	388,205	3,680,953	1,041,131
1970-1989	175,459	453,984	453,984	611,272	634,492	n/a	777,829	877,520	388,205	3,680,953	1,041,131
1990-2007	110,816	286,727	286,727	386,067	400,732	n/a	491,260	554,223	245,182	2,324,812	657,557
Mobile Homes	**24,666**	**63,821**	**63,821**	**85,932**	**89,196**	**103,493**	**109,346**	**123,361**	**54,573**	**517,464**	**146,361**
Before 1969	9,373	24,252	24,252	32,654	33,895	39,327	41,552	46,877	20,738	196,636	55,617
1970-1989	9,373	24,252	24,252	32,654	33,895	39,327	41,552	46,877	20,738	196,636	55,617
1990-2007	5,920	15,317	15,317	20,624	21,407	24,838	26,243	29,607	13,098	124,191	35,127
Total	**1,849,326**	**4,784,970**	**4,784,970**	**6,442,779**	**6,687,513**	**5,822,066**	**8,198,276**	**9,249,014**	**4,091,665**	**38,797,050**	**10,973,469**

Appendix 7 NPVE and Levelised Eo

Conservation Project	Applicable CO2 Reduction (t CO2e)	Net CO2e flow (t CO2e)	T (yr)	NPVE (t CO2e)	% Rate	Levelised *Eo* (t CO2e)
M1: Heating equipment	(1.230)	-1.230	20	-13.66	6.4%	(1.230)
M2: Windows	(0.287)	-0.287	20	-3.19	6.4%	(0.287)
M3: Weather stripping	(0.144)	-0.144	5	-0.60	6.4%	(0.144)
M4: Insulation around hot water pipes	(0.076)	-0.076	20	-0.84	6.4%	(0.076)
M5: Programmable thermostat	(0.615)	-0.615	10	-4.44	6.4%	(0.615)
M6: Solar water heater	(0.466)	-0.466	20	-5.17	6.4%	(0.466)
M7: Heater blanket on water heater	(0.047)	-0.047	10	-0.34	6.4%	(0.047)
M8: Dual flush system	(0.073)	-0.073	20	-0.81	6.4%	(0.073)
M9: Low flow showerhead	(0.183)	-0.183	10	-1.32	6.4%	(0.183)
M10: CFL (per 3 bulbs)	(0.054)	-0.054	5.5	-0.24	6.4%	(0.054)
M11: Indoors clothes drying	(0.155)	-0.155	1	-0.15	6.4%	(0.155)