Policies to reduce urban GHG emissions: Accounting for heterogeneity of demographics, values, and urban form

by

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Abstract

This research project evaluates actions and examines associated policies to reduce emissions in the city of Vancouver, British Columbia, Canada. The project takes a standard policy evaluation approach using cost-effectiveness, emissions reduced, political acceptability, and administrative feasibility. It then considers intangible values as well as demographic and urban form interactions. Taking these interactions into account illustrates how the evaluation may change given different demographic characteristics or urban density levels. The results show that while research into these additional factors is limited, there is potential for them to inform policy evaluations in the future.

Keywords: urban emissions; urban energy; policy evaluation; intangible values; demographic preferences; policy planning

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List of Acronyms

BCUC	BC Utilities Commission
DE	District Energy
GHG	Greenhouse gases
IPCC	Intergovernmental Panel on Climate Change
LEED	Leadership in Energy and Environmental Design
MATA	Multi-attribute trade-off analysis
OECD	Organization for Economic Cooperation & Development

Chapter 1.

Introduction

Over half of the world's population currently lives in urban areas and by 2030 that number is expected to reach two-thirds (OECD, 2008). As urban populations continue to rise the amount of energy needed to sustain these areas will increase, along with greenhouse gas (GHG) emissions if the combustion of fossil fuels continues to dominate the global energy system. Urban areas account for 71-76% of carbon dioxide emissions from final energy use (Seto et al., 2014). As a result, there is increasing interest in the potential for cities to reduce emissions.

The built environment is an enduring feature in our cities that can significantly affect energy use and emissions for decades. Improving building design and operations, or altering urban form and land use can potentially reduce emissions. Recognizing this potential, municipal leaders in North America and around the world have stated objectives to reduce emissions from their built environments. Vancouver, British Columbia adopted a Greenest City Action Plan in 2011, with ambitions to reduce GHG emissions 33% by 2030 and 80% by 2050 (Vancouver, 2015). This was followed in 2015 by a commitment to obtain 100% of its energy from renewable sources by 2050.

Municipalities can take three types of actions to reduce emissions in their built environments: 1) energy efficiency 2) energy conservation and 3) fuel-switching. In the popular press and even at times in academic literature, these concepts are used interchangeably. Distinguishing between these three actions is the first step in addressing the complexities of energy use and emissions reductions.

1.1. Background

1.1.1. Energy Efficiency, Conservation and Fuel Switching

Energy Efficiency

In technical terms, energy efficiency is the ratio of useful energy output to energy input. As efficiency improves, people receive the same or better quality of energy services (outputs) with less energy inputs. A more efficient car drives farther for the same amount of gas. A high-efficiency air conditioner uses less electricity to cool the same space. In both of these cases, the user does not sacrifice comfort for energy savings.

Efficiency improvements do not always result in energy reductions. One explanation for this is the rebound effect. William Jevons first discussed this in 1865 when he realized more efficient steam engines actually caused an acceleration of Britain's coal consumption rather than the expected reduction. Efficiency improvements decreased the cost of steam-powered coal extraction, thereby increasing its use. Direct rebound effects occur when efficient technologies result in people using the technology more, diminishing actual energy savings. For example, installing a high-efficiency furnace reduces heating costs and may cause people to maintain a higher temperature level in their homes. Indirect rebound effects occur when the cost savings from efficient technologies are used to purchase other energy-intensive services. People may not use their new high-efficiency furnace more, but they use the money saved on energy bills to pay for flights to exotic vacation destinations or an extra television set. These additional expenditures have energy implications that can erode or even override efficiency improvements.

Energy Conservation

Energy conservation and efficiency are often confused; however, they create distinct differences in the user experience. Conservation focuses entirely on reducing energy use by decreasing the level of energy services, while under efficiency the level of service remains the same. Rather than install a high-efficiency light bulb, a user would simply use the existing bulb less to conserve energy (Jones & Zoppo, 2014).

The majority of energy conservation opportunities lie in behaviour change. Turning off unnecessary lights, lowering the thermostat, or using appliances less are common conservation strategies. These actions typically come at no or very low cost to the user, but they present additional challenges. As most conservation actions rely on human behaviour change, their success is dependent on individual preferences and lifestyles. Energy consumption is woven into our everyday lives, and conservation must alter that everyday life in order to be successful (Wilson & Dowlatabadi, 2007).

Fuel Switching

While efficiency and conservation seek to limit energy use, fuel switching focuses on changing the type of energy used to power goods and services. By switching to a lower-carbon energy source, emissions are reduced without decreasing the amount of energy used or the quality of services delivered.

Fuel switching can have a large impact on emissions regardless of how much energy is used. From 1990-2010, while Canadian residential energy use increased 6%, associated GHG emissions fell 0.5% as utility systems switched to less GHG-intensive fuel sources (NRCan, 2013). Both small- and large-scale renewable electricity supply technologies are available. Small-scale generating units can create a distributed network of technologies located close to the loads being serviced, reducing transmission losses (McLean-Conner, 2009). At the larger grid-scale, switching utility systems over to nuclear, hydroelectricity or other technologies can reduce emissions across the existing grid. Fuel switching is also possible at the personal level. In the transportation sector for example, consumers may switch to electric or plug-in hybrid vehicles, or shift from gasoline personal cars to low-carbon electricity-powered public transit.

Simply undertaking any of these three energy actions may not necessarily reduce emissions. If energy is already supplied by a low-carbon source such as hydroelectricity, nuclear, or solar, then conservation or efficiency will have a negligible impact on emissions, and switching the energy source may increase emissions. Switching from a 90% efficient gas boiler to a 100% efficient electric heater will increase emissions if that electricity comes from a fossil fuel power source (Herring, 2006). Conversely, switching from a 90% efficiency gas-fired combined heat and power system to electricity that runs resistance heaters or heat pumps will reduce emissions if the electricity comes from hydropower, wood waste, wind, or geothermal electricity generating stations. In British Columbia, where most electricity comes from low-carbon hydroelectricity, actions that focus on high-carbon fuel sources such as gasoline for vehicles will have a more significant impact on emissions than a campaign to turn off lights or switch to solar-powered electricity systems.

1.1.2. Actions

Municipal governments can take a variety of actions to reduce emissions in their built environment. Six potential actions guide this research project: 1) retrofitting existing buildings 2) constructing new buildings 3) increasing urban density 4) increasing mixed-use development 5) expanding public transit, and 6) expanding or creating district energy systems.

Retrofitting existing buildings and constructing new buildings can reduce emissions through fuel switching or efficiency. Fuel switching may include installing heat pumps and/or electric baseboard heaters instead of gas furnaces, or other technologies that alter existing energy sources. Efficiency actions maintain existing energy sources, but upgrade appliances or features to use less energy while maintaining the quality of delivered energy service. Although fuel-switching is an important action, there is less literature available on its impact; therefore a large amount of evidence presented relates to efficiency. While mostly the same technical options apply to both retrofits and new buildings, there may be more options in the case of new buildings as contractors are less restricted by pre-existing building design or technologies.

Increasing urban density concentrates buildings around existing municipal services. This may reduce emissions through a combination of energy efficiency and conservation in one of three ways: reducing vehicle use, reducing energy use in buildings, or reducing required services. Similarly, mixed-use development alters urban form; but instead of solely increasing the amount or height of buildings in an area, mixed-use creates a variety of building types and uses within a single area. This can include mixing employment and residential use, mixing various types of housing, or mixing different social functions. Mixed-use development can reduce emissions primarily through conservation. By condensing business, retail, and residential services into single complexes rather than dispersed through a city, vehicle trip rates or vehicle miles travelled per trip can be reduced (Koster & Rouwendal, 2002; Ewing & Cevero, 2001).

Public transit may reduce emissions through a combination of fuel switching and energy conservation by increasing travel options and accessibility. People forgo using their personal vehicles (thereby reducing vehicle miles travelled) in favour of commuting with low-carbon public transit. Increased energy efficiency is also possible by improving existing transit technologies, although this option is not explicitly covered in this research project.

District energy systems use centralized plants to generate thermal energy for hot water and space heating and cooling in urban areas. They reduce emissions primarily through a combination of efficiency and fuel switching. District energy can be a very efficient energy source: conventional power stations convert only about 35% of their input fuel energy into electricity, while district energy systems can convert up to 85% of the input energy into cogenerated heat and power. Both renewables and fossil fuels may power these systems, and, as a result, emissions reductions from district energy systems occur only when fuel is switched to lower carbon sources.

1.1.3. Policies

When a municipal government decides to pursue a specific action such as increasing density or improving transit, it must then decide which policy it will use to try to achieve that objective. Policies can be categorized based on the degree to which they are compulsory, leading to three types: regulations, economic instruments, and information (Mickwitz, 2003; Vedung, 1998). Regulatory policies impose practices or technology to reduce emissions. Economic instruments attempt to overcome market failures by increasing the relative economic attractiveness of certain actions. Information policies use awareness and education to encourage people to adopt more actions that reduce emissions (Sunikka, 2006). Table 1 lists policies in each of these categories that municipalities may use to reduce emissions.

Table 1: Potential municipal policies

Regulatory	Economic	Information
Building standards Building codes Zoning Urban growth boundaries Road-entry restrictions Urban planning mandates Bylaws	**Incentives:** Tax credits/breaks Loans Subsidies Grants Innovative financing **Disincentives:** Taxes Development cost charges Impact fees Vehicle charges	Voluntary certifications Public leadership Information campaigns Detailed billing/feedback Auditing

As listed above, there are many policies to choose from. Both energy efficiency and fuel switching can be encouraged through technology subsidies, grants, loans, or tax credits. Regulations may mandate minimum efficiency or fuel source requirements. Zoning regulations can specify transit accessibility requirements, mixed-use development, and minimum densities. Bylaws, information, or technology subsidies may increase the prevalence of district energy systems. Information campaigns or auditing can demonstrate the benefits of many different types of efficiency, fuel switching, or conservation actions.

Governments face risks when deciding amongst both actions and policy options. They may spend time and money on actions that fail – for example, expanding public transit in areas that do not have a strong demand for the service, or focusing on new building regulations rather than retrofits in areas where the building stock turnover is low. They face additional risks when selecting policies: an energy tax can place low-income groups at a disadvantage and result in political backlash, while a subsidy with a large amount of free-ridership (people accepting money for actions they would have taken regardless) wastes government resources.

Comprehensive evaluations help avoid these unintended outcomes while achieving emission objectives. While there are a number of possible evaluation criteria, actual evaluations are limited due to a lack of time, resources or other constraints. At a minimum, most evaluations try to measure cost and environmental effectiveness. Other possible criteria include equity (is it fair), policy duration (how long do the effects last), administrative feasibility (how easy/hard is it to implement), and political acceptability (will stakeholders support or oppose the action/policy). The following four criteria are common to many evaluation frameworks: 1) environmental effectiveness 2) cost-effectiveness 3) administrative feasibility and 4) political acceptability (Canada, 2012; Jaccard, Rivers, & Horne, 2004).

Large gaps in research limit evaluation potential. These include practical concerns regarding low quality data and limited records on how much actions and policies may cost or reduce energy consumption (Gillingham, Newell, & Palmer, 2006; Ó Broin, Nässén, & Johnsson, 2015; Suerkemper, Thomas, Osso, & Baudry, 2012). Improved monitoring and enforcement can mostly address the practical concerns. Other concerns; however, are less studied and more difficult to estimate. Two of these more abstract concerns are intangible values and heterogeneity with respect to demographics and urban form.

Intangible values are not usually included in evaluations; instead, cost effectiveness estimates measure financial costs such as administrative costs, equipment costs, and/or energy cost savings. Intangible values can be positive or negative depending on the context. Improved air quality provides positive intangible values through reduced mortality and morbidity rates. While reduced air quality results in negative intangible values due to increased respiratory problems or other concerns. A car has a positive value for convenience, whereas public transit can have a negative value due to lack of privacy, limited mobility, or inconvenience. While efficiency investments can help improve comfort levels, they may also come with negative intangible values such as the additional risk people accept when they install new technologies, quality deficiencies in these technologies, or the additional hassle of researching and finding a qualified contractor for installation.

Heterogeneity is another concern. In the context of this research, heterogeneity refers to both demographic variation and urban form variation. Demographic heterogeneity refers to the varying values people in different demographic groups hold towards actions. Non-compulsory policies encouraging dense development, public transit, or home retrofits are only successful if these actions are desired. Ignoring the citizens who place less value on certain actions could offset any benefits. For example, despite ongoing densification in United States city-centres, the enduring values that some citizens hold for lower-density suburban living has been found to generate increases in emissions that completely offset emissions reductions gained through city densification (Jones & Kammen, 2014). Age, income level, and family size are all demonstrated to affect responses towards energy actions (Banfi, Farsi, Filippini, & Jakob, 2008; Howley, 2009). However, despite recognition by some researchers of a need to tailor policies to different demographic populations, energy policy evaluations generally do not consider demographic variation.

Urban form heterogeneity refers to variation in the built environment. This can be measured in terms of density, building type mix, infrastructure or transportation systems. This project focuses primarily on density as an indicator of urban form. These existing urban features can affect future policy success. For example, expanded public transit or mixed-use development in low-density suburban areas may have a limited impact on actual emissions if there are insufficient population levels to sustain the developments. Heterogeneity of demographics or urban form is of little importance if the variation is quite small. However, we do not fully understand the effect of this variation because it has not been systematically studied (Clark, 2013; Heinonen, Jalas, Juntunen, Ala-Mantila, & Junnila, 2013).

As mentioned earlier, the city of Vancouver has ambitious plans to reduce emissions in the next 35 years. However, the city has a diversity of people and urban forms within its boundaries and this diversity, if ignored, could derail its greenest city plans. Using the city of Vancouver as an example, this research aims to evaluate actions and their associated policies to reduce emissions in the built environment. The evaluation considers the typical financial, environmental, administrative, and political evaluative criteria, while also considering intangible values and heterogeneity with respect to demographic characteristics and density as a measure of urban form.

1.2. Research Approach

The research framework, summarized in Figure 1, consists of two literature reviews, matrix analysis, a study application, and multi-attribute trade-off analysis. The first literature review examines financial cost and benefit analyses, information on energy or emissions reduced, and any available estimates of intangible values for the six actions or policies that support them. The second literature review examines demographic and urban form variation. Each of these literature reviews then inform matrices that organize the findings according to 1) financial impact 2) intangible impact 3) emissions reductions and 4) demographic and density interactions.

I also examine the political acceptability and administrative feasibility of the actions specifically for Vancouver given its population, legislative, and other local circumstances. In the application stage, I group neighbourhoods according to shared demographic and urban form characteristics to create four area profiles. I apply the information found in the second literature review to each area profile. This creates four distinct demographic and urban form matrices that contain information later used as an additional evaluative criteria. I then conduct a multi-attribute trade-off analysis to evaluate the actions. Finally, I discuss policy implications for Vancouver and other British Columbian municipalities based on my findings.

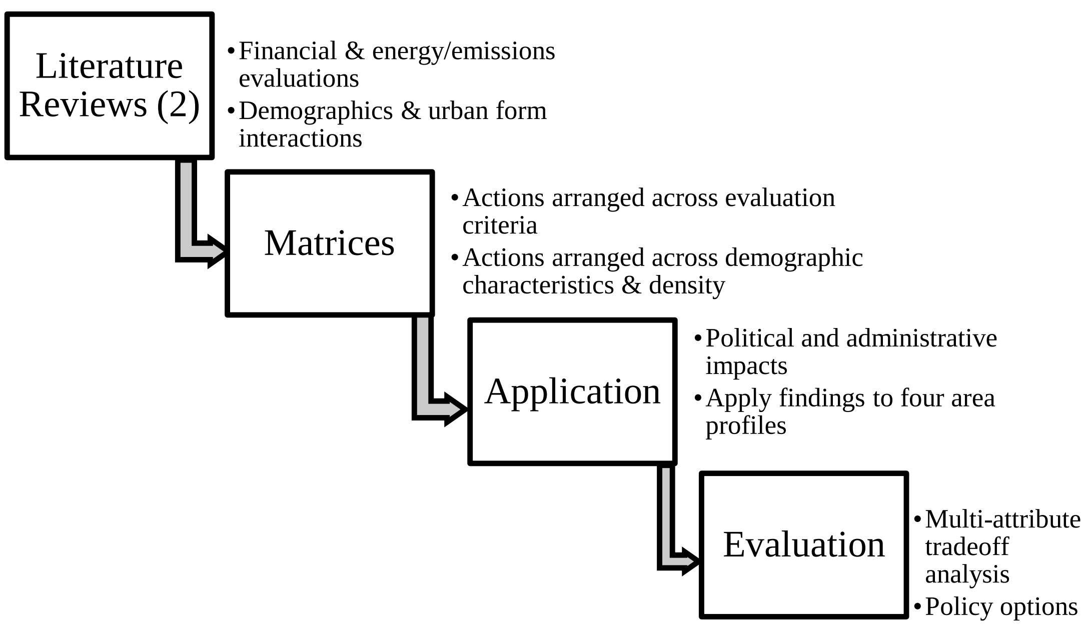

Figure 1: Research framework

1.2.1. Methodology

Literature Reviews

The first literature review includes evaluations of the actions, and if available, policies that encourage those actions in the built environment. Emphasis is on peer-reviewed academic meta-analyses from recognized journals. Due to a lack of data, when needed the review was expanded to include other studies, conference proceedings papers, and in some cases, government policy evaluations. In the case of information relating specifically to district energy systems, I use reports from the Pacific Institute for Climate Solutions due to a lack of relevant evaluations in academic journals. The second review includes some peer-reviewed academic studies on the impact of demographic and urban form variations for each action. Due to a lack of data, I expanded the review to include consulting surveys by the Pembina Institute, the Canadian Energy Efficiency Association, and the American Real Estate Association.

Matrices

In order to organize the literature review results, I define methods of rating the data, summarised below and represented in Figures 2, 3, and 4.

Financial and Intangible Impacts

I attempt to evaluate both the tangible (financial) and intangible impacts of the actions and associated policies. The tangible impacts are covered in standard evaluations. These measure the financial cost-effectiveness of actions or policies usually as a comparison of costs to energy or emissions costs saved. This is not a measure of economic efficiency, which measures the difference between overall benefits and costs (Arrow, Cropper, Eads, & Hahn, 1996). In economic theory, economic efficiency only occurs when there are no public goods, no externalities, no information problems, and a number of other conditions (Fullerton & Stavins, 1998). This project uses cost-effectiveness as it was the most commonly-used measurement in the literature. Intangible impacts are determined based on a review of intangible values for different actions and policies in the built environment. The ratings outlined in Figure 2 apply for both financial and intangible impacts and include ‘negative’, ‘somewhat negative’, ‘variable’, ‘somewhat positive’, and ‘positive. A ‘negative’ rating indicates consistent agreement in the literature of costs significantly outweighing benefits. A ‘somewhat negative’ rating indicates some agreement in the literature of costs slightly outweighing benefits. A rating of ‘variable’ indicates inconsistency within the literature, with some studies showing costs while others find benefits. ‘Somewhat positive’ indicates some agreement in the literature of benefits slightly outweighing the costs. Finally, a ‘positive’ rating indicates fairly consistent agreement in the literature of benefits substantially outweighing costs.

Rating	**Description**
Positive	Significantly higher benefits than costs
Somewhat Positive	Slightly higher benefits than costs
Variable	Varying possible benefits and costs
Somewhat Negative	Slightly higher costs than benefits
Negative	Significantly higher costs than benefits

Figure 2: Financial and intangible rating scale

Emissions Reductions

I take the energy reductions found in the literature review and then infer the potential to reduce emissions given Vancouver’s local context. The ratings in this case are ‘high’, ‘moderate, ‘low’, and ‘inconclusive’. If there is evidence that indicates substantial reductions are possible, then potential is high. If the evidence indicates reductions are low in comparison to other actions that is rated as low. If reductions may be more variable, where some estimates are high but others are low, potential is variable. In the case of inconclusive, I did not feel confident making a determination either way due to a lack of reliable information.

Rating	**Description**
High	Studies show significant reductions.
Moderate	Studies show variable reductions.
Low	Studies show marginal reductions.
Inconclusive	Not enough information to rate.

Figure 3: Emissions reduction rating scale

Demographic & Urban Form Ratings

To represent how values may vary with demographic characteristics, I assign the ratings of ‘negative’, ‘somewhat positive’, ‘positive’, and ‘inconclusive’ to each action as it relates to the following demographic characteristics: income, family size, and age. A negative rating indicates that an action is negatively associated with the demographic characteristic in question. For example, if studies consistently show a desire for most people to move out of dense areas once their incomes are high enough to do so, this is a negative association between high incomes and high density. Positive associations follow a similar logic: if studies consistently show a link between younger ages and higher values for dense dwellings, then that is a positive association. The same rating scale applies to urban form. In this study I focus only on one measure of urban form – density as measured in people/hectare.

Icon	Relationship	Description
✓✓	Positive	Surveys show a positive association
✓	Somewhat Positive	Surveys show a potential positive association
×	Negative	Surveys show a potential negative association
**	Inconclusive	Studies produce highly conflicting results or not enough data to determine association

Figure 4: Demographic & urban form rating scale

Study Quality

These rating schemes rely on my judgements of not only what the study data shows, but also the quality of the research and resulting data. In this research, I must interpret findings that are at times conflicting, and use results from different methodologies, sources, and situations. Not all studies are equal in comprehensiveness, quality, and validity. Therefore, I also try to be mindful of quality and other concerns such as scope, context, and susceptibility to bias when interpreting the primary research findings. For these reasons, throughout the study whenever I make judgements I give a summary of my conclusions and reasoning.

Application to Vancouver

Political Acceptability & Administrative Feasibility

In Chapter 2 I rate political acceptability and administrative feasibility of the actions or policies according to the particular legislative, municipal, and public environment in Vancouver. This evaluation creates similar rankings as those identified for economic, environmental, and demographic criteria. This section reviews academic studies but also government, business, and utility company reports and websites. The data informing this section is less comprehensive and more subjective than the literature reviews. In my evaluation, I assume a typical application of actions and policies within a municipal setting.

Local Area Profiles

I define Vancouver local area profiles based on 1) median age; 2) average household income; 3) family size and 4) density. Figure 5 lists definitions for each of these demographic characteristics.

Demographic & Density Definitions (as described in Canada Census definitions)
Age: refers to the age of a person at their last birthday. All age measurements are median population age. **Family size:** refers to the number of persons per household. **Income:** refers to the total income from all sources minus federal, provincial, and territorial income taxes paid for the reference year. Income is measured at the household level in this research, so household income is the sum of the after-tax incomes of all members of that household. This study uses average household income. **Density**: Number of people per hectare.

Figure 5: Demographic & density definitions

All information comes from the 2006 & 2011 Canadian census surveys and the city of Vancouver Open Data Catalogue. Separating Vancouver neighbourhoods according to this information creates four area profiles to which I apply with the information from both literature reviews. The four resulting profiles are used as the basis for a multi-attribute trade-off analysis in Chapter 4.

Evaluation

Chapter 4 includes a multi-attribute trade-off analysis (MATA) which evaluates the actions according to the evaluative criteria. MATA can apply where a decision maker or evaluator is ranking a limited number of alternatives measured by two or more criteria. In this case I act as an evaluator ranking the different actions Vancouver may use to reduce emissions. The different rankings for each profile can help highlight which actions are best suited to each demographic-urban form profile, not just within Vancouver, but potentially in other British Columbian municipalities as well.

The MATA consists of four steps: 1) specification of the goal and criteria; 2) specification of the criteria ratings; 3) specification of preferences for the criteria ratings and evaluative criteria weights; and 4) ranking of the alternatives according to the specified preferences.

In this research project, the alternatives are the six actions previously identified. The evaluative criteria consist of 1) financial impact 2) intangible impact 3) emissions reductions 4) political acceptability 5) administrative ease and 6) demographic/urban form interaction.

Criteria ratings are the different ratings for each criterion previously described in this section. The preferences for the criteria ratings are numerical values I have assigned to represent the relative desirability of each rating. For example, higher emissions reductions are more desirable than lower emissions reductions and are assigned a higher preference value. The evaluative criteria weights are numerical weights I assign to specify which of the criteria (financial, intangible, emissions, political, administrative, or demographic) are most desirable. These numerical values allow me to carry out the MATA using a utility function formula shown in Equation 1.

Equation 1. MATA Utility Function

$$U(x^1, x^2, x^3, x^4, x^5, x^6) = w^1 * u^1(x^1) + w^2 * u^2(x^2) + w^3 * u^3(x^3) \ldots + w^6 * u^6(x^6)$$

$$where\ w^1 + w^2 + w^3 + w^4 + w^5 + w^6 = 1$$

This formula creates scores for each action. In the equation, *w* refers to the weight I assign to each evaluative criteria, while *u* refers to the numerical preferences of criteria ratings (higher emissions reductions versus lower emissions reductions, for example). The figure x represents each evaluative criteria, while the total (*U*) is the sum across all evaluative criteria for each action. I repeat this process four times to account for every area profile. A sensitivity analysis also examines the impact of different weights on the ranking results.

Finally, once the MATA is complete I discuss the action rankings and potential policy ramifications for Vancouver and other British Columbian municipalities.

Chapter 2.
Literature Reviews

2.1. Economic Impact & Emission Reductions

This section reviews evaluations of financial cost effectiveness, intangible values, and emission reductions in relation to the six actions. While most studies have evaluated energy reductions, as noted previously that does not necessarily translate into emissions reductions. Throughout this section, after I review energy reduction estimates for each action, I discuss the emissions-reduction potential for Vancouver given its local energy sources and current policy environment.

2.1.1 Existing Buildings

Financial Cost-Effectiveness

Evaluations on policies targeted towards retrofitting existing buildings mainly review economic incentives and information programs, although retrofitting actions can also be mandated through regulatory policies. Most retrofit incentives seem relatively cost-effective when measured in terms of program costs and energy saved (Rezessy, Dimitrov, Urge-Vorsatz, & Baruch, 2006; Rosenow & Galvin, 2013). In a review of the UK's Energy Efficiency Commitment Schemes, Rosenow & Galvin (2013) estimate the cost for delivering policies at 0.007 Euros/kWh, lower than the market cost of delivering the energy. However, the authors note household investment costs were not included in this estimate, when participants were likely required to pay for at least a percentage of the investments. A French study of a subsidy and tax credit program for fuel switching investments in wood stoves and boilers, solar hot water heating systems, heat pumps and efficiency investments in double glazed windows found the program to be cost-effective for participants (Suerkemper, 2012). This study considered the energy bill savings, incentive payments, and costs of the investment for participants. The most cost-effective investments were fuel switching actions: condensing boilers and wood stove investments. The least cost-effective measures were double glazed windows. However, windows were also the most popular investment, suggesting people may be getting other intangible benefits from this type of investment than those evaluated, such as reduction of external sound. In a global review of policies to encourage fuel switching and efficiency investments Urge-Vorsatz (2009) found subsidies, grants and loans ranged from US$-66/tonne of CO_2 in (negative) costs to end-users (only considering energy costs saved) and up to $105/tonne of CO_2 in costs to society (considering program costs and energy costs saved).

Information policies to encourage retrofits show more variable evidence of cost-effectiveness. In an evaluation of a UK television, radio, and online advertising campaign, Murray (2010) conducts a door-to-door survey asking respondents about their energy savings, if they recalled the ad campaign, and whether the campaign influenced their actions. Murray then estimates energy savings from those self-reported actions. He finds the program to be cost-effective, although the study omitted discussion on how actions convert into estimates of energy savings, so it is difficult to check the methods for accuracy or bias. Urge-Vorsatz (2009) finds a range in information policies with lows of US$-66/$tCO_2$ in Brazil to a high of US$8/$tCO_2$ in the UK. This wide variation may suggest costs depend on program delivery or other contextual factors such as local culture or political climate. Some researchers have found evidence that information campaigns targeted at lower income groups may be ineffective if not accompanied by economic instruments (Wade & Eyre, 2015). Overall the cost-effectiveness of retrofits in existing buildings seems somewhat positive, with economic incentives showing more cost-effectiveness than information policies.

Intangible Values

Economic incentives that encourage retrofitting investments are associated with intangible costs. For example, in order to receive loans, grants or subsidies, recipients must first know the programs exist, determine eligibility, book an audit if required, select the appropriate investment, hire a contractor, and in the case of loans, manage an additional repayment bill. The amount of required paperwork for these actions can be substantial, placing large demands on time and decision-making abilities. These represent transaction costs of the programs.

Based on available data, the intangible costs of undertaking energy efficiency and fuel switching investments may be high. Michaelowa & Jotzo (2005) estimate transaction costs of energy efficiency to be as high as 20.5% of investment costs for building envelope investments, while fuel switching intangible costs may be as high as 14.4%. Kiss & Mundaca (2013) estimate the intangible costs of investing in CFL lightbulbs at 10% of the bulb costs, while cavity wall insulation costs are estimated to be 30% of the investment price. Furthermore, assistance throughout the process may not be enough to overcome the costs. In an analysis of the United States' Weatherization Assistance Program, which provides subsidies and information specifically to low-income groups, Fowlie (2015) finds that even when assisted, people still opt to not undertake cost-effective retrofit investments which had an average value of $5,000 in energy savings. There is limited quantitative evidence; however, the available data seems to show that intangible costs of retrofitting existing buildings are relatively large. It is unclear whether there is a difference in intangible costs between retrofit actions and similar actions when a new building is constructed, though intangible costs may be lower in new buildings because of fewer restrictions related to accommodating existing building design and technologies, as well as the existing inhabitants.

On the other hand, investments in energy efficiency may bring intangible benefits. There is a consistent, although somewhat variable price premium for more energy-efficient buildings ranging from 3-13% (Popescu, Bienert, Schützenhofer, & Boazu, 2012). Buildings officially certified through independent agencies such as LEED or EnergyStar command a slightly higher minimum price premium of 5%. In addition, there are many other co-benefits of improved energy efficiency: reduced energy infrastructure costs, improved health, and local employment. Clinch and Healy (2003) estimate 21% of the total benefits from efficiency investments were due to improved comfort. In another study, Clinch estimates that energy benefits represent 57% of total program benefits, followed by health (25%), additional comfort (10%), and emissions reductions (10%). Researchers find a net social benefit from retrofits at various discount rates (0-10%) (Clinch & Healy, 2001). I found no available evidence on the intangible benefits of fuel switching investments.

Overall, while there are intangible benefits associated with energy efficiency investments, the intangible costs of both energy efficiency and fuel-switching investments may be high. I have rated the impacts as variable in recognition of these differences.

Energy & Emissions Reductions

When estimating energy reduced from retrofits, there is evidence of a gap between technical estimates and actual results, ranging from 40-70% of the expected savings (Wade & Eyre, 2015). In a sample of over 300 homes, Bundgaard (2013) finds subsidies reduced energy use by about 44% of the level estimated by the program. In an evaluation of an Irish retrofit scheme, Scheer & Clancy (2011) find reductions were 22 – 25% lower than estimates. In a review of the UK's Warm Front Program, which provides subsidies and grants to low income households for insulation, fuel-use was reduced 10-17% when the models predicted reductions of 45-49%. Sunikka-Blank and Galvin (2012) term this problem the 'pre-bound effect', a situation where dwellings use less baseline energy than what is modelled, resulting in lower-than-estimated savings from efficiency investments. As a result, models of potential energy reductions tend to overestimate savings. In addition, free riders can also cause actual reductions in energy to be lower than even *ex-post* estimates indicate. Under free-ridership, consumers or firms receive subsidies for efficiency or fuel switching actions they would have undertaken without the subsidies. Neither energy nor emissions are reduced below what would otherwise have occurred, and as a result the subsidy is ineffective. Free ridership rates can be very high. In a review of Canadian energy efficiency subsidies, Rivers and Shiell (2014) find rates of around 70%. Keeping these additional factors in mind, while studies indicate that retrofits do reduce energy use, the amount is usually lower than estimations predict.

Vancouver's electricity system is largely based on low-carbon hydroelectricity. Space heating in BC is 39% electricity-based and 55% natural gas-based, with the remaining other fuel sources being biomass and oil (NRCan, 2013). Retrofit actions that reduce energy use will only have the potential to reduce emissions if they focus on natural gas-heavy end-uses such as space or water heating.

In Vancouver, renovations over $5,000 require consultation with a certified energy advisor; however, consultation is simply an information program and these have a very poor record of causing emission reduction actions. Renovations are only subject to permitting if they impact major structural features such as walls, additions, accessory buildings, or alterations to plumbing, electrical, or gas lines. In other cases, such as door or window replacement, there is no method to verify that all renovations meet current building codes. Therefore at present, the impact of regulations on emissions at this level is limited. This could be improved with stronger regulations that mandate fuel-switching during renovations. In addition, despite the potentially high energy reductions that can come through economic incentives to retrofit existing buildings, the city of Vancouver relies on third-party programs that may or may not specify the fuel sources to be targeted. Economic incentives are not mandatory and apply only to those interested and aware of the programs. Furthermore, they can have high rates of free ridership. There is large potential in to mandate fuel switching actions during renovations. However, currently the city of Vancouver does not use these options. I discuss the potential of improved regulations in the concluding comments. Given previous evidence that suggests actual energy savings from retrofits are lower than estimates, in addition to a lack of strong regulations on retrofits in Vancouver and limited impact of economic incentives and information policies, estimated current emissions reductions for existing buildings are low.

2.1.2 New Buildings

Financial Cost-Effectiveness

Evaluations for efficient new buildings primarily focus on regulatory measures, however these results may also apply to existing buildings if cities enact similar policies for retrofitting. Building standards and codes are relatively cost-effective at reducing GHG emissions, when measured in terms of program costs and energy saved (Ó Broin et al., 2015; Suerkemper et al., 2012; ürge-Vorsatz, Koeppel, & Mirasgedis, 2007). In a meta-analysis of sixty *ex-post* policy evaluation reports, Urge-Vorsatz (2009) finds best practice costs for regulations ranged from US $-5 to -189 per tonne of CO_2. A meta-review of the United States Building Energy Code Program administered by the US Department of Energy estimates $400 in savings for each dollar spent on building energy codes, measured as a comparison of program costs to estimated full-fuel cycle energy savings to consumers (Cole, Livingston, Elliott, & Bartlett, 2014). In an analysis of 250 energy efficiency building policies in European Union countries, Broin (2015) finds regulatory measures to be the most effective and suggests they be given a high priority in future policy consideration. All studies, including academic and government sources, found regulations to be moderately or highly cost-effective when measured in terms of program costs and energy saved.

Intangible Values

In most cases with intangible values, it is not possible to distinguish between retrofits and new construction. Since most evaluations focus on building regulations, here I provide an overview of the potential intangible costs of these policies. Building regulations present a number of challenges, particularly to developers and building contractors. A government survey of British Columbian contractors, architects, developers, and builders identifies numerous concerns that may represent negative impacts of these policies. Stakeholders state that a lack of specialists, expertise, resources, and time limits their ability to meet building code requirements. They are also concerned with frequent code changes causing confusion and new technologies that are not properly modelled in existing design software (Province of BC, 2014). While not quantitatively estimated, these factors represent transaction costs of regulations that may contribute to lower than expected code compliance rates and decrease policy impact. In British Columbia, Tiedemann (2012) finds compliance rates of 63% during on-site investigations of 187 dwellings while in the United States, compliance rates range from 0-73% (Williams, Vine, Price, Sturges, & Rosenquist, 2013). There is no evidence available regarding intangible costs to homeowners of new construction and, presumably, intangible benefits similar to those found with retrofitting (increased comfort, reduced morbidity) would apply. Intangible impacts are rated somewhat positive, slightly higher than the intangible benefits for existing building actions.

Energy & Emission Reductions

There is fairly robust academic evidence that building regulations modestly reduce energy use, but actual reductions are likely to be significantly lower than technical *ex ante* estimates (Meijer, Itard, & Sunikka-Blank, 2009; Rosenow & Galvin, 2013). *Ex ante* measurements refer to estimates of energy that could be saved, and are taken before program implementation, while *ex post* measurements occur after program implementation and are a better gauge of actual energy saved. In a review of seven European Union country building codes, Saussay (2012) demonstrates a statistically significant increase in energy efficiency in all countries since building codes were implemented. Saussay finds the effect of codes increased over time, but also noted the potential for declining returns as the building stock gradually improves in efficiency. In a review of Denmark's building standards program Kjaerbye (2009) finds an efficiency improvement of 7% where the technical program estimations anticipated 25% reductions in natural gas use. In an Irish evaluation of 1997 and 2002 homes built to different standards, Rogan & O Gallachoir (2011) find the 2002 homes had actual efficiency improvements of 10%; compared to the technical estimate of 20%. In contrast to the previous studies, Deason & Hobbs (2012) estimated the overall impacts of British Columbia building standards and found reductions of 10%, higher than the technical estimates of 5%. While the results are variable, all surveyed studies find energy reductions from building codes, despite discrepancies between anticipated and actual reductions.

Most building standards in BC and Vancouver relate to space heating concerns such as ventilation, windows, and air tightness. Currently, there may be greater opportunity for emissions reductions from individual new homes than retrofits due to stronger existing regulations for new buildings, weaker regulations for renovations, and the opportunity to install new technologies without the restriction of accommodating an existing building design. Reductions can theoretically be as high as 100% if the regulations are designed to do so. However, that potential is limited by political acceptability resulting from the higher costs builders and developers face when trying to meet increasingly stringent building standards. Emissions reductions are rated as moderate.

2.1.3 Density

Financial Cost-Effectiveness

Density cost-effectiveness is normally measured in comparison to traditional alternatives such as dispersed or suburban development. Strict financial analyses of density tend to find cost-effectiveness. Three meta-analyses of dense development find it costs less with respect to road and utility costs, but may be the same or even slightly more expensive when delivering schools. Road costs of dense development range from 40-93% of the cost of sprawling development, utility costs ranged from 60-92% and school costs ranged from 97-102% (Burchell, 1997). Mukherji (2003) finds sprawl increases public service costs about 10% and housing developments about 8%. An analysis of 2,500 Spanish municipal budgets find low-density neighbourhoods increase per capita costs of providing local services (Hortas-Rico & Solé-Ollé, 2010). However, Gordon, a critic of density argues that the few available studies on costs reveal a u-shaped cost function that bottoms at relatively low residential densities, below 1,250 people per mile (Gordon & Richardson, 2008). Most studies show some cost-effectiveness of density.

Intangible Values

Many researchers point to substantial non-economic benefits of dense development including lower land consumption, resource protection and improved access to services (Beatley & Manning, 2000). Density is also associated with increases in neighbourhood walkability, declines in obesity, heart disease, and diabetes (Frank & Pivo, 1994). There is evidence that in more dispersed urban areas, limited access to community facilities, services, and employment can have negative impacts (Ewing, 1997).

However, density may also be accompanied by neighbourhood problems and dissatisfaction (Howley, 2009). There are also housing affordability concerns. In British Columbia, housing affordability is found to decline with increases in density (Quastel & Moos, 2012). Jones (2015) finds developers are demolishing affordable rental apartments near Burnaby skytrain stations in favour of denser high-rise condominiums, and in the process displacing low-income immigrant families from what is otherwise a highly valued neighbourhood.

Furthermore, hedonic price studies show people generally prefer to live in larger homes and are willing to pay price premiums to do so when incomes allow (Bajari & Kahn, 2004; Olaru, Smith, & Taplin, 2011). Bajari & Kahn (2004) find increasing density in Los Angeles and decreasing lot sizes 10% would lower average utility by $1,119 dollars per year. They find almost all of the negative utility comes from homebuyers living in smaller homes, not lot sizes. If the lot size shrinks without shrinking home size, people on average are better off by about $2,000 a year due to the decreased commuting times. With shrinking lot sizes, however, there are issues with on-street parking, noise, loss of privacy, and impacts on the neighbourhood character that were not considered in the study.

Because of the variation in intangible values with respect to density, it is challenging to make a conclusive statement on whether the benefits outweigh the negative impacts in all circumstances. A proportion of the population is clearly amenable to denser dwellings, smaller lot sizes, and smaller homes. However, the most consistent quantitative evidence in this area shows price premiums for more space in houses, streets, and blocks and this evidence is recognized even by proponents of denser development (Ewing, 1997; Gordon & Richardson, 2007). For this reason, the negative impacts outweigh the benefits when strictly considering denser development patterns. I discuss demographic variation as it relates to density further in section 2.2.

Emissions Reductions

There are three major ways density can reduce energy use and its resulting emissions. These are reduced vehicle use, reduced energy use in buildings, and by reducing services required in cities. There seems to be common agreement that density can reduce city infrastructure requirements by condensing them in smaller areas (Chao & Qing, 2011). The other two claims have been consistently under examination in academic literature.

The relationship between density and energy-related transport emissions is complex, limited and variable across urban areas (Clark, 2013). While Handy (2005) and others find residents of dense areas drive less, other researchers have noted a paradox of intensification, where increasing population densities increase the concentration of vehicle use on the intensified areas, causing local environmental and social problems

(Parkhurst, & Barton, 2011). While there may be increases in local air pollutants, overall there seems to be a reduction in GHG emissions.

While density may reduce energy use in buildings in certain studies, this result can change drastically with units of measurement and reporting scopes. An empirical assessment of energy use and GHG emissions of high and low-density residential development in Toronto finds the measurement unit may alter results significantly. Measuring emissions per unit of living space, suburban areas are just 1 – 1.5 times more emissions-intensive than city-centres, with the difference being mostly due to increased emissions from transportation in lower density areas, not from building energy use. When measuring emissions on a per capita basis, emissions in suburban areas are 2 – 2.5 times as intensive as high density development (Wilson et al., 2013).

Reporting scopes are another consideration. Many studies omit indirect energy and emissions associated with consumption of goods such as food or clothing and services such as airline transportation. Incorporating these indirect effects can alter results substantially and researchers are recognizing a need to include the full impacts of consumption on energy use (Seto et al., 2014). The Energy Information Administration (EIA) (1991), in an analysis of data from 1984, 1987 and 1990, shows that detached single-family homes used roughly 18-20% more energy than multi-unit homes, and used nearly 80% more than housing units in large buildings (those with more than five units). However, the EIA does not adjust for differences in square footage, income, or other controls that are often part of the comparison in other studies, and only considered energy for heating, cooling, and appliance use. In contrast, after comparing the emissions of Finnish capital Helsinki against the less dense area of Porvoo and finding the denser Helsinki produces more emissions, Heinonen (2012) concludes that simply packing people into denser urban forms is not sufficient for effective city-level carbon management.

While some studies have found emissions reductions from density are significant, other studies that take broader reporting scopes argue that those reductions are overestimated. In the case of this study, I focus instead on the broader reporting scopes that include consumption as part of the emissions calculations. Density is necessary in many cases as a way to encourage other emissions-reducing actions such as transit expansion, but increasing density itself may not necessarily reduce emissions. Therefore, the emissions-reducing potential of density alone is rated low.

2.1.4 Mixed-Use

Financial Cost-Effectiveness

Mixed-use development shows more variation in cost-effectiveness, which changes based on location. In denser and more populous cities such as Vancouver or Toronto, it can be profitable. In small cities or areas that are less familiar with mixed-use development, it can be risky for developers to take on mixed-use projects. It is significantly more expensive to build and service, particularly in the initial planning and construction stages, but can also provide better returns if there is demand (Rabianski & Clements, 2007). In smaller cities or suburban areas, it may not create a premium value for sales and developers may struggle to sell units. McKenzie Towne, a mixed-use development project touted by urban planners as the future of urban planning for Calgary, boasted a range of housing types, commercial property and a proposed light rail station. Once built, developers struggled to sell commercial spaces and leased them out instead with high vacancy rates. Resident opposition forced a private school out of the complex and the developer ultimately cancelled plans for more apartments because market rents would not cover the costs (Grant, 2002). Other projects in Toronto that focus more on a mix of housing types are more successful and consistently sell at high prices. While mixed-use development can be a profitable venture, many developers are hesitant to build in suburban areas and usually for good reason. In large cities like Vancouver, mixed-use is usually financially lucrative despite requiring longer development periods, substantially higher equity requirements, and high upfront capital costs (J. S. Rabianski & Clements, 2007). Though it may have trouble competing with simpler property investment options, particularly in smaller cities or highly dispersed neighbourhoods. Financial cost-effectiveness is rated as variable.

Intangible Values

Proponents of mixed-use development suggest a number of benefits: neighbourhood revitalization, increased housing stock, facilitated transit use, and increased accessibility. These and other benefits contribute to building sale price premiums. A mix of land uses such as business and leisure activities may increase housing values up to 6% in urban areas. The negative effects (noise, light, traffic, trash) depress the price of immediately adjacent houses as much as $14,453 while accessibility benefits result in a $9,675 premium. Additionally, mixed-use development can contribute to gentrification, opening up infill sites for redevelopment into upscale residential buildings that drive out lower-income groups. Housing costs may escalate, vacancy rates decrease and homelessness can become a concern (Grant, 2002). Developers too face barriers. Mixed-use buildings are more difficult to finance than single use development and the multitude of business services creates additional complexity in the planning process. As a result of these and other factors, investors sometimes perceive mixed-use development as a higher risk investment (Rabianski, 2009). Intangible values are rated as variable.

Energy & Emissions Reductions

Studies on mixed-use development show increased emissions in comparison to conventional development in terms of building energy use, although the extent to which mixed-use development can support other emissions-reducing strategies such as transit and district energy may assist in overall emissions reductions (Tong & Wong, 2011.). Modeling by Ewing (2007) in a six-region study in the United States finds mixed-use development with diverse activities reduces GHG emissions from traffic relative to conventional suburban developments. As noted with density, these relationships are variable depending on specific situations. Mixed-use development in suburban areas will not reduce emissions as much as similar development in already dense areas. While I initially rate the emissions reducing potential as low, I comment on the interactive effects of mixed-use with other development forms in my concluding comments.

2.1.5 Transit

Financial Cost-Effectiveness

Cost-effectiveness is a concern for transit systems. Public transit is subsidized by governments. In an evaluation of United States light rail systems, Guerra and Cevero (2011) find most systems are not cost effective, while Frank (1994) finds systems are only cost effective at densities ranging from 20-75 employees per acre. In Canada, the results are similar: the most cost-effective system in Canada is Toronto's GoTransit, with a cost recovery ratio of 80%, followed by Montreal (57%) and Vancouver (52%). Highest cost recovery ratios in the United States are in San Francisco, Washington, and Philadelphia, which range from 60-65%. Transit can be profitable in areas with very high urban population densities. In Hong Kong, Taipei, and Singapore transit systems generate a profit (BC Auditor General, 2013). To be fair, no passenger transportation system covers all of its costs without government funds, including highways and roads (Vuchic, 2005). Without extremely high population densities, transit in most cases is not a profitable investment from a strictly financial perspective and is given a negative rating.

Intangible Values

Intangible values of transit can include benefits from accessibility, mobility, as well as costs from a lack of privacy, limited travel options, or inconvenience. Again, quantitative research is limited. A number of meta-analyses have tried to estimate the effect of transit accessibility on residential home prices. Most find positive relationships, but a small number indicate a negative relationship in certain circumstances (Guerra & Cevero, 2011). Cevero's (2002) review shows price premiums for housing within ¼ to ½ miles of rail transit stations of between 6.4 - 45% compared to housing outside of the transit area. Another meta-analysis of 57 studies concludes residential property values increase 2.4% for every 250m closer to transit rail stations, yet in the case of bus stations, data show a price discount for nearby properties (Debrezion, Pels, & Rietveld, 2007). Overall, studies tend to show price premiums for light rail transit stations and variable results for bus transit. Intangible impacts are rated as somewhat positive.

Energy & Emissions Reductions

Analysis of the environmental benefits for transit is generally positive. Nahlik & Chester (2014) reviewed new rail and bus transit systems in Los Angeles and found potential GHG emission reductions of up to 470 $GgCO_2e$[1] and a decrease in user costs of $3100/household/year despite the higher rental costs in the transit-serving areas. Transit

[1] Gigagrams of carbon dioxide-equivalent (1 gigagram = 1,000,000 kilograms)

as a method of reducing vehicle transportation has high potential to reduce emissions. Light rail transit emits less than half the emissions of CO_2 per passenger mile as private cars, and bus transit emits about 2/3 the emissions (Department of Transportation, 2010). Additionally, while not considered in the scope of this study, which focuses on the built environment, switching from gas-powered personal vehicles to hybrid or electric models can have large impacts on emissions while ensuring people still have a variety of choices in their personal transportation modes. Emissions-reduction potential from public transit is rated moderate.

2.1.6 District Energy

Financial Cost-Effectiveness

While some propose district energy as a highly profitable alternative to conventional systems, in practice the net financial costs seem more variable. In a review of seven district energy systems in British Columbia, Ostergaard (2012) estimates the cost per megawatt hour paid by residential customers of seven district energy systems for heat and hot water in 2011, plus comparable costs for BC Hydro electric heating and Fortis gas. He finds that the costs to the customer of the systems, in particular newer ones, may be higher than conventional systems. District energy systems also may have high upfront costs. Despite these issues, Ostergaard finds that the district energy providers can be confident of a revenue stream through the life of the systems. Though he also notes that from the consumer's perspective, energy efficiency investments can provide comparable energy services and GHG reductions at similar costs. Financial cost effectiveness is rated as somewhat positive.

Intangible Values

Because there is a single centralized boiler, district energy systems eliminate the need for a boiler or furnace in each serviced building. As a result, they are about 1/5th the area of conventional systems and so free up space for other uses and reduce noise from mechanical rooms. Furthermore, they can ease retrofitting time and costs by requiring the retrofit of just one central energy centre rather than hundreds of small boilers in large complexes or campuses. They can also provide a platform to share the risks of adopting new technologies by spreading costs out amongst many buildings. Despite these benefits, research on two Ontario district energy projects finds that the development of a district energy system is a complex process, requiring the expertise of many specialists and support from local stakeholders. Drawbacks of district energy include lack of energy choices and sometimes-higher rates. There are also major planning implications of district energy systems which require forethought by government (Bradford, 2012). Furthermore, while the systems do spread the risk out amongst customers, specific district energy projects in British Columbia have found customer dissatisfaction with recurring system technical failures (Ostergaard, 2012). Intangible values are therefore rated as somewhat negative.

Emissions Reductions

For district energy systems, there is a wide range of potential emissions reductions based on project size, type, and energy source. For example, a natural gas-sourced system with oil backup in Vancouver estimates zero GHG emissions reduced, while a natural gas and biomass system at Simon Fraser University estimates 10,000 tonnes of CO_2/yr reduced (Ostergaard, 2012). Of fifteen district energy systems in BC, Ostergaard (2012) finds eleven of those systems reduce at least some GHG emissions. The remaining four systems that do not show reductions are natural gas-powered or did not have the information available. The only system rated as emitting GHG's was Central Heat Distribution (now known as Creative Energy) in downtown Vancouver, because of its reliance on natural gas. District energy has potential to reduce emissions as long as it uses low-carbon fuel sources. A review of BC district energy systems shows the majority rely on non-fossil fuel sources for their primary energy source or have plans to switch in the case of Creative Energy. Therefore, the emissions-reducing potential of district energy for Vancouver is estimated to be moderate.

2.2. Matrix – Review #1

The following matrix in Table 2 summarizes the information from the previous literature review.

Table 2: Financial, Intangible, and Emissions Impacts

	Existing Buildings	New Buildings	Density	Mixed-Use	Transit	District Energy
Financial Impacts	Somewhat Positive	Positive	Somewhat Positive	Variable	Negative	Somewhat Positive
Intangible Impacts	Variable	Somewhat Positive	Negative	Variable	Somewhat Positive	Somewhat Negative
Emission Reductions	Low	Moderate	Variable	Low	Moderate	Moderate

Summary of Estimates

Building retrofits encouraged mainly through economic incentives or information policies show evidence of cost-effectiveness. Economic incentives may be more cost-effective than information policies, although both are rated somewhat positive. While intangible costs of retrofitting measures may be quite high, there are also demonstrated benefits associated with increased comfort. However, those benefits only seem to apply to energy efficiency, not fuel switching investments. Intangible values are rated as variable. Emissions reductions potential is rated low due to a discrepancy between estimated and actual energy savings, potential for free ridership with economic incentives, and generally low energy reductions from information policies.

New buildings subject to regulations may be more cost-effective than economic incentives or information policies for retrofits. New building occupants may experience intangible benefits of efficiency investments, without the intangible costs associated with economic incentive mechanisms such as applying for loans, subsidy, or grant schemes. Therefore intangible benefits are rated somewhat positive. As all new buildings in Vancouver are subject to relatively strict regulations, emissions reductions are rated as moderate. There is potential for higher emissions reductions from regulations; however, intangible costs to developers can impact compliance rates, and without strict monitoring and enforcement they will likely be less than estimated. In addition, because existing regulations are relatively strict, there is less potential for continuous improvement in this area.

Density is financially profitable; though it may come with high intangible costs related to quality of life, pollution, and congestion. Emission reductions are variable due to the differing study results when accounting for scales, reporting scopes, and calculation methods. However, density is important to encourage other actions such as transit, mixed-use development, and district energy.

Mixed-use development research shows intangible benefits for health, quality of life, and walkability, in addition to moderate financial benefits. However, these financial benefits are location-specific and developers may face higher intangible costs. Emission reduction potential is low, although there is potential for mixed-use development to support other emissions-reducing actions such as transit.

Because transit rarely recovers its full costs and relies on government subsidies, financial impact is rated negative. Intangible benefits are somewhat positive due to improved home sales prices near transit stations and some potential health benefits associated with transit. However transit may also have intangible costs associated with increased commuting times, the inconvenience of waiting, and the loss of privacy or status when people give up their personal vehicles. Emissions reduction potential is rated as moderate due to the lower emissions in comparison to private vehicles.

District energy has moderate financial benefits, though again this is dependent on specific systems. Intangible costs are somewhat negative due to the complexity of developing and managing these systems, the additional risk involved in building and using them, and the potential for technical failure. A review of BC district energy systems shows most reduce emissions; therefore, this potential is rated moderate.

2.3. Demographic and Urban Form Literature Review

This section examines how people's responses to the six actions may vary with age, income, and family size, and how actions may interact with density. When possible, I focus on surveys of Vancouver residents to maximize the relevance for application.

Researchers note a general lack of understanding of the demographic and social factors that play a role in energy efficiency and fuel-switching actions (Friege & Chappin, 2014; Judson & Maller, 2014). Data availability in this area is limited; however, what is available provides some helpful clues as to where some people's values may lie and how these may differ under certain circumstances.

2.3.1 Existing Buildings

In a survey of Canadians regarding retrofit investments for energy efficiency, the Canadian Energy Efficiency Association (CEEA) finds that while all groups were equally interested, higher income groups were more likely to engage in more costly measures. Lower income groups were practicing more 'low cost' behavioural change actions rather that investing in efficiency or fuel switching. A significant barrier to retrofitting, particularly for low income groups was the belief that retrofits are not worth the effort for too little savings, suggesting that economic incentives may help encourage action. Furthermore, fuel switching actions that do not reduce energy costs may not be well-received by these groups without additional incentives. Similarly, a Swedish study of retrofit behaviour explores the relationship between income and propensity to undertake retrofits (Nair, 2010). Low-income groups are least likely to invest, while mid-income groups were more likely than high-income groups to invest. It is unknown the extent to which these outcomes are the result of values held by specific demographic groups, or rather the constraints that low-income groups face. Nair suggests that economic incentive mechanisms may be better suited towards low-income groups to overcome the discrepancy in uptake. Other studies also support this suggestion while noting a higher potential for free-ridership with higher income groups (Galvin, 2014).

Nair (2010) finds those most likely to adopt energy efficiency or fuel switching retrofits, both on their own and with incentive programs, were between 36 and 45 years of age. Older groups (ages 60+) were least likely to implement measures. In terms of family size, American government researchers note greater potential energy savings in larger households (Woo & Guldmann, 2011). The results suggest that retrofits are more positively associated with mid-age ranges and larger families. Lower income groups are less likely to engage in retrofitting actions and, while higher income groups are more likely to invest, they are also most likely to be free riders of incentive programs.

2.3.2 New Buildings

No demographic or urban form information is available specifically relating to new building actions.

2.3.3 Density

Childless young adults and older empty nesters are found to be more likely to prefer dense living (Myers & Gearin, 2001). A number of surveys agree that younger singles who aren't looking to purchase homes are more likely to prefer dense living within a city centre (Winston, 2013). Yang (2013) also finds that those over 65 express a higher level of agreement with the willingness to trade off house size for proximity to amenities. In an Irish survey, Senior (2006) finds few households would consider moves to denser development in the city or redeveloped docklands, and those that would consider the moves were mostly seniors or younger couples. However those 'preferences' may be the results of income constraints. Dawkins (2009) finds that despite first-time homebuyers' characteristics of having lower incomes and younger ages, they do not seem to express stronger preferences for housing located in denser areas, and instead search first for affordable housing.

In stated preference surveys, Winston (2013) and Howley (2009) find preferences of those already living in dense areas were weighted towards ultimately living in areas with lower density once they had the financial means to do so, with the push to move coming strongest from families. Liao et al. (2014), Howley (2009), and Winston (2013) all find those with families or the intention to start families preferring lower density development. Laio finds that, in Utah, stronger preferences for suburban neighbourhoods mainly occur among bigger families with school-aged children and high-income households. The results at this scale suggest that younger people, smaller households, seniors, and lower income groups may prefer or be more constrained towards density.

2.3.4 Mixed-Use

Mixed-use shows high preferences across most demographic characteristics, particularly for Vancouver (Frank, Kershaw, Chapman, & Perrotta, 2014). Although, preferences in the city of Vancouver are not the same as preferences in the surrounding municipal areas. While 53% of Vancouver respondents preferred a mix of different housing types in their neighbourhoods, only 29% of respondents in the outlying metro Vancouver neighbourhoods shared this preference. This type of development is not ideal in dispersed locations with limited accessibility; therefore, there is a positive association with density in relation to mixed-use development. In a survey of Toronto residents, the Pembina Institute (2014) finds that when housing costs are not a factor, 81% of respondents choose to live in an urban or suburban neighbourhood where they can walk to stores, restaurants or other amenities.

2.3.5 Transit

Public transit is generally valued among younger age groups, lower incomes, and smaller family sizes. In a study of Metro Vancouver, researchers found 60% of respondents strongly preferred design features that support walking and public transit, with these preferences higher in the younger (under 35) age groups (Frank et al., 2014). Families with children showed slightly higher preferences for less-dense neighbourhoods.

Singles, those with no children, and those ages 60 and over or 18-34 value a pedestrian and transit-friendly city more according to the Pembina Institute (2014) survey. People with children, married, and ages 35-59 valued suburban living more. Lewis (2010) found a major constituency for transit-oriented development is lower income groups and younger ages.

2.3.6 District Energy

No demographic information is available specifically relating to district energy systems, though district energy shows higher financial profitability when combined in denser urban settings and mixed-use development such as large academic or corporate campuses.

2.4. Matrix – Review #2

The matrix in Table 3 depicts the relationships between each demographic characteristic and each action.

Table 3: Demographic/density interaction matrix

	Existing Buildings	New Buildings	Density	Mixed-Use	Transit	District Energy
Lower Income	✕	**	✓	✓	✓✓	**
Higher Income	✓	**	**	✓	**	**
Smaller Household	**	**	✓	**	✓	**
Larger Household	**	**	✕	**	**	**
Younger Ages (<40)	**	**	✓✓	✓✓	✓✓	**
Mid-Age (40-65)	✓✓	**	**	✓	*	**
Older Ages (65+)	**	**	✓	✓✓	✓	**
Low density Areas	**	**	**	✕	✕	✕
Dense Areas	**	**	**	✓	✓	✓

The studies examined in the literature review indicate that higher income groups are receptive to building retrofits; however, the potential for free-ridership is greater with high-incomes. Lower income groups are less responsive to retrofits; however, economic incentives may help improve the uptake. Mid-age groups have a somewhat positive association due to results showing they are more interested and engaged in learning about efficiency or fuel-switching investments. Density is positive for younger ages and somewhat positive for lower incomes, smaller households, and older ages. Mixed-use is somewhat positive for all incomes and all ages, with positive results especially for younger and older age groups. Mixed-use is potentially negative for lower density areas due to studies suggesting a ‘disamenity’ effect where commercial mixed-use development is less desirable in lower density neighbourhoods. Transit is rated as positive for younger ages, lower incomes and somewhat positive for older ages and smaller households. The demographic interactions for district energy systems are unknown, though it is preferable to locate systems in denser areas.

2.5. Administrative Feasibility & Political Acceptability

This section will assess the level of administrative ease and the political acceptability, or likelihood of strong support or opposition to actions or policies encouraging the actions. The ratings for administrative ease and political acceptability are very low, low, moderate, and high.

2.5.1 Existing Buildings

Administrative Ease

Economic incentives for retrofit actions may be more difficult to implement if they require negotiation or partnerships with banks, utility companies or other stakeholders to implement the programs. One issue with economic incentives is the amount of monitoring and enforcement required. Loans require repayment systems and subsidies necessitate application processes and funding administration. Furthermore, with the high chance of free-ridership, agencies need to ensure some way of limiting the incentives to those who are least likely to carry out the desired action otherwise.

There is also the option of introducing innovative financing schemes. Innovative financing options include property tax and utility bill financing. These programs provide upfront capital for homeowners, who then repay loan interest and principal in installments. These policies present particular issues with respect to administrative feasibility. In the case of property tax financing, repayment is made as part of a voluntary property tax assessment. The loan transfers between owners upon sale of the home. The city of

Vancouver's legal department believes that while this form of financing is supported by the city's Charter, there is a small chance it could be challenged in court leading to loan defaults and open the city to risk (Bierth, Peyman, & Svedova, 2010). Utility financing is similar, but administered through utility companies instead of municipal government and uses the monthly utility bill as a way to collect loan repayments. Currently, no legislation in BC permits on-utility bill financing that is transferable between owners. It also requires consultation and partnership between the municipality and the utility company, in addition to approval through the utility regulator.

Due to all of the factors described above, the administrative ease for encouraging retrofits primarily through economic incentives is rated as moderate.

Political Acceptability

Political acceptability of incentives or information to encourage retrofits is likely to be high as there is no negative impact on the public in the form of a fee or charge, while acceptability of taxes or other charges to encourage retrofits is likely to be low. Because the city only seems to focus currently on incentive and information policies, the political acceptability in this case is rated as high.

2.5.2 New Buildings

Administrative Ease

The city of Vancouver is in a unique position to control the efficiency of its building stock through bylaws. Its Charter provides the city with the ability to enact bylaws that mandate efficiencies. City council approves new bylaws or amendments to existing bylaws. These amendments do not normally require consultation with other governments, making changes in this area relatively straightforward from the perspective of local government. While regulations may be straightforward to enact, the issue of enforcement may create an administrative burden on city staff, given limited resources. Administrative ease in the case of new builds is rated as high.

Political Acceptability

Compulsory policies such as regulations are far less politically acceptable than economic incentives, while economic disincentives are the least popular of all. Rhodes, Axsen & Jaccard (2014) find citizen support for regulations is higher than for economic disincentives such as carbon taxes. There is no evidence of strong public opposition to building regulations in particular, though there are some documented concerns where builders and contractors must meet new regulations every few years and may be required to meet standards they view as unfeasible or impractical. This can impact compliance rates and potentially affect political acceptability if stakeholders see the regulations as exceptionally unreasonable. With this in mind, I have rated the political acceptability of new building actions through regulations as moderate.

2.5.3 Density

Administrative Ease

Vancouver has the authority to tie project approvals to specific performance requirements such as density and mixed-use development. In addition, rezoning can encourage both density and mixed-use development. City staff initiate rezoning following a change in policy or when the public makes a rezoning application. Zones are customized to specific sites, changed from one zone to another standard zone, or amended. Planning staff review the applications, and then report to city council, where council either approves or refuses the applications. While procedures to change zones, create new zones, or approve density bonusing are straightforward, they normally require research and public consultation, which can increase the administrative burden. Zoning and density bonusing policies are regulatory policies similar to building standards. Administrative ease for density action is moderate.

Political Acceptability

While Vancouver is a relatively dense city, increasing density has been a contentious topic in the past. Rosol (2013) traces how some types of density increases in some areas has faced opposition from residents, community groups, and social activists concerned with gentrification and housing affordability.

Former mayor Sam Sullivan proposed the EcoDensity initiative (2006-2009) to extend densification throughout the city with the goal of improving livability, environmental performance and housing affordability. City planners conducted two years of workshops, community meetings, public forums, and fairs attracting thousands of participants. Concerns that density would simply mean more condominiums for high-income professionals dominated the consultations (Bula, 2008). EcoDensity met with a reluctance of many residents to embrace the initiative. Because of the lack of support, a municipal government change in 2008 dropped the EcoDensity initiative and replaced it with the greenest city goals. These goals focus on bike paths, community gardens, composting and emergency beds for the homeless. The new government also pushed forward with relaxed height and density requirements for developments that provide rental-only towers, sold off lands for dense development and promoted infill as well as mixed-use development without the strong branding of EcoDensity.

Vancouver's low vacancy rates suggest there is still a considerable level of demand for existing dense development in the city. To minimize public opposition of new dense development, community members and stakeholders must be engaged early and often in the development projects. Though even when consulted, there is no guarantee residents will be receptive to increased density. Because of this, increasing density may have low political acceptability.

2.5.4 Mixed-Use

Administrative Ease

Mixed-use development is encouraged at the city level in the same manner as density with zoning regulations or development charges. The city of Vancouver has complete jurisdictionally authority over this development; however, as with density, there is usually some level of public consultation involved when rezoning for mixed-use. Therefore administrative ease is rated as moderate.

Political Acceptability

While density and mixed use are generally supported with the same policies and public consultation processes, there is no record of similar strong opposition to mixed-use development. However, mixed-use development requires minimum densities; therefore, the opposition to density may also affect mixed-use development. Accounting for this dynamic, the political acceptability for mixed-use development is slightly higher than density, at moderate.

2.5.5 Transit

Administrative Ease

Vancouver is part of the broader Metro Vancouver transit system managed by Translink. Any changes to Translink revenues, routes, or other operating procedures typically require consultation or approval from the province, mayor's council, and the Regional Transportation Commissioner, in addition to extensive public consultation. To improve or change transit service, the city of Vancouver must lobby Translink and the provincial government, in addition to consulting with the 21 other municipalities that make up Metro Vancouver. The recent tax referendum failure highlights the difficulty in initiating changes to public transit. Making changes to transit in British Columbia is a relatively time-consuming process that requires multiple levels of consultation and partnerships. Administrative ease is low.

Political Acceptability

Transit improvements that affect area residents or require tax increases (as in the case of Vancouver's recent transit referendum) can face large public opposition. The negative impacts of public opposition include delayed projects, lack of funding sources, or low use of the infrastructure once it is built. Because of these considerations, political acceptability of transit actions is low.

2.5.6 District Energy

Administrative Ease

District energy systems can be challenging to build without government support, regulations, and subsidies. Within BC, the BC Utilities Commission regulates most systems unless a local government provides the service. Changes to the Vancouver Charter have made it easier for the city to undertake or encourage district energy systems; though there is still a large burden in terms of administration, oversight, and management of these systems. Consultation with local area residents and businesses is also required, in addition to cooperation with provincial utility companies. Administrative ease is moderate.

Political Acceptability

Public awareness of district energy systems is low, and this can influence political acceptability. When Vancouver city staff were planning the Southeast False Creek Neighbourhood Energy Utility, they held a number of public consultations and workshops to gauge support. The public consultation process found public perception was not always based on technological facts. The public was apprehensive about the construction of what some thought of as an industrial facility near a high-density residential neighbourhood, as well as concerns about technical failure (The Challenge Series, 2010). District energy systems, in addition to transit improvements, suffer from NIMBY-thinking (not in my backyard). This refers to cases where certain infrastructure improvements are negatively valued by nearby residents, even if they provide important area benefits. Opposition to these types of infrastructure can be fierce (Hyslop, 2005). Because of these factors, political acceptability of district energy is low.

Table 4 summarizes the findings for financial and intangible impacts, emissions reductions, administrative ease, and political acceptability.

Table 4: Evaluation summary

	Existing Building	New Buildings	Density	Mixed-Use	Transit	District Energy
Financial Impact	Somewhat Positive	Positive	Somewhat Positive	Variable	Somewhat Negative	Somewhat Positive
Intangible Impact	Variable	Somewhat Positive	Negative	Variable	Somewhat Positive	Negative
Emissions Reductions	Low	Moderate	Variable	Low	Moderate	Moderate
Administrative Ease	Moderate	High	Moderate	Moderate	Low	Moderate
Political Acceptability	High	Moderate	Low	Moderate	Low	Low

Thus far, the evaluation has included four major evaluation criteria: financial impacts, emissions reductions, political acceptability, and administrative ease. It has also identified demographic and density interactions to apply to Vancouver and considered intangible values. The next section defines the area profiles used in the final evaluation and applies information from the demographic and density matrix.

Chapter 3.
Application to Vancouver

This section creates a sixth evaluative criteria metric relating to demographic and urban form interactions.

3.1. Local Area Profiles

Vancouver consists of twenty-two local planning areas. These areas all have their own demographic profile and urban form, though they share some common characteristics. Based on similarities in median age, household income, family size, and density, the planning areas have been grouped into four profiles (Table 5): 1) Downtown, 2) West, 3) East, and 4) Mixed.

Table 5: Area Profiles

	Average Income (2006)	Median Age	Family Size	Density (People/hectare)
Downtown	$60,298	37	1.68	121
East	$60,657	41	2.92	54
West	$155,822	44	2.66	28
Mixed	$63,627	40	2.30	46
Vancouver (City)	$68,271	40	2.20	52

Figure 6 illustrates how the local planning areas are spatially grouped. The green areas are Profile 1: Downtown; blue areas are Profile 2: West; red areas are Profile 3: East; orange areas are Profile 4: Mixed; and the two greyed out areas have been left unassigned due to characteristics that do not match with the other local area characteristics. These two areas have very high median ages in comparison to other neighbourhoods, and Strathcona in particular has a very low average income. Oakridge most closely resembles the West profile; however, the average income level is $20,000 lower than the lowest income of all local areas in the West, and is over $15,000 higher than the highest income in the East.

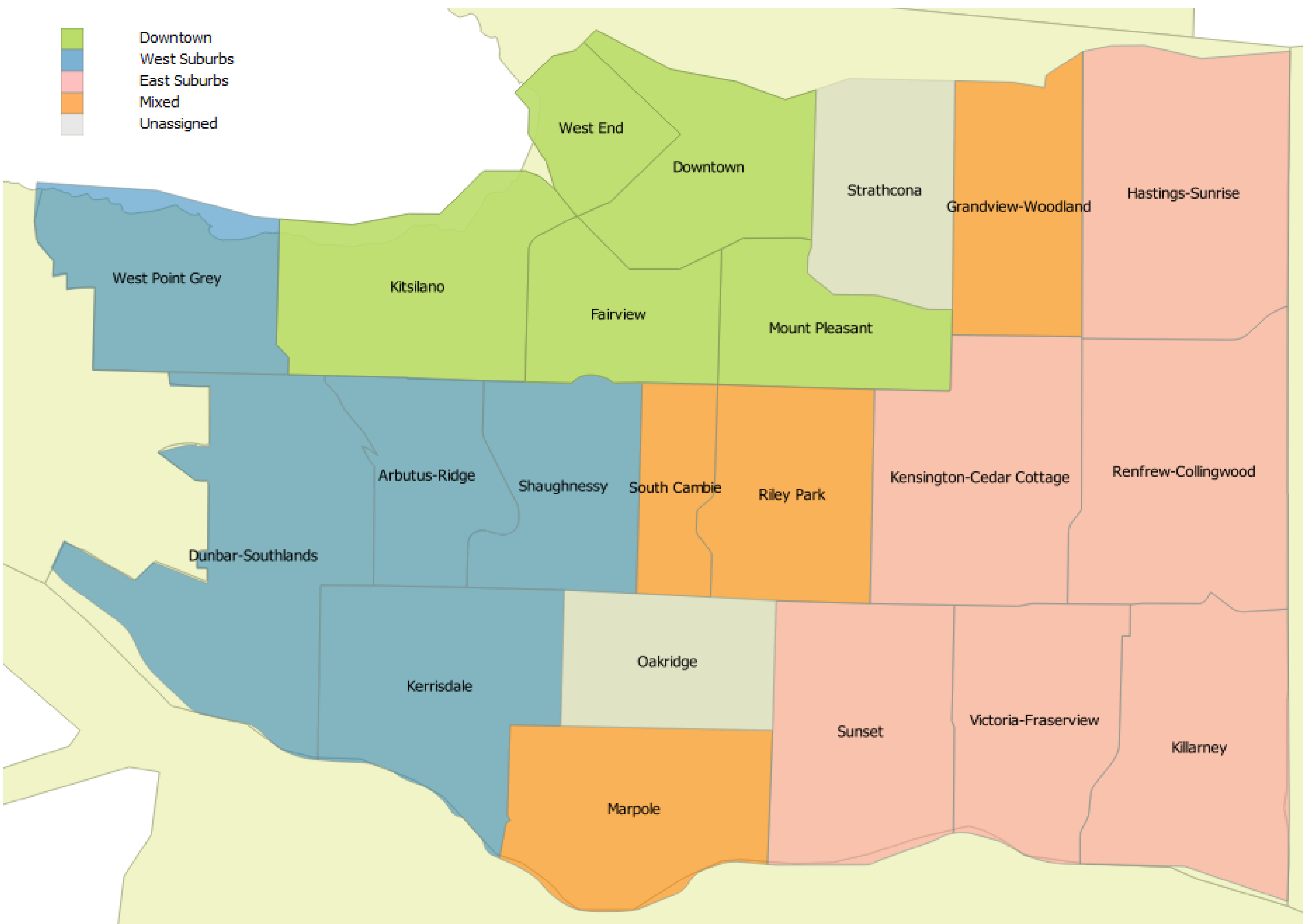

Figure 6: Map of local area profiles

Application of findings to profiles

I apply the results from the matrix in section 2.4 to each of the four area profiles, listed in Tables 6 through 9. The lack of information, specifically relating to new buildings and district energy affects the results at this stage. The actions each have a 'base score' of 4 points, with every somewhat positive interaction increasing the score by one point, and a positive interaction increasing the score by two. Negative interactions reduce the score by one point. The resulting scores serve as the sixth criteria in the multi-attribute trade-off analysis (MATA) that follows.

Profile 1 - Downtown: The Downtown group includes the West End, Downtown, Mount Pleasant, Fairview, and Kitsilano. These areas have a lower than average household income, smaller family size, highest density, and the youngest median age of all four cases.

Table 6: Downtown profile

	Existing Building	New Buildings	Density	Mixed-Use	Transit	District Energy
Lower Income	✗	**	✓	✓	✓✓	**
Younger Ages (<40)	**	**	✓✓	✓✓	✓✓	**
Smaller Family Size	**	**	✓	**	✓	**
Dense Areas	**	**	**	✓	✓	✓
Score	3	4	8	8	10	5

Profile 2 - West: The West group includes West Point Grey, Dunbar-Southlands, Kerrisdale, Arbutus-Ridge, and Shaughnessy. These areas have the highest incomes, the oldest median age, lowest density, and the second-largest family size.

Table 7: West profile

	Existing Buildings	New Buildings	Density	Mixed-Use	Transit	District Energy
Higher Income	✓	**	**	✓	**	**
Older Ages (65+)	**	**	✓	✓✓	✓	**
Larger Family Size	**	**	✕	**	**	**
Lower Density	**	**	**	✕	✕	✕
Score	5	4	4	6	4	3

Profile 3 - East: The East group includes Hastings-Sunrise, Renfrew-Collingwood, Killarney, Sunset, Victoria-Fraserview, and Kensington-Cedar Cottage. These areas have slightly higher than average ages, average density, the largest family sizes, and lower incomes than average.

Table 8: East profile

	Existing Building	New Buildings	Density	Mixed-Use	Transit	District Energy
Lower Income	✕	**	✓	✓	✓✓	**
Mid-Age (40-65)	✓✓	**	**	✓	*	**
Larger Family Size	**	**	✕	**	**	**
Average Density	**	**	**	**	**	**
Score	6	4	4	6	6	4

Profile 4 Mixed: The Mixed group includes Marpole, South Cambie, Riley Park, and Grandview-Woodland. These are areas with a mix of income ranges, ages, and slightly lower density. Average income ranges from slightly above to slightly below Vancouver's average. Family size and median age are about average in comparison to Vancouver as well.

Table 9: Mixed profile

	Existing Building	**New Buildings**	**Density**	**Mixed-Use**	**Transit**	**District Energy**
Average Income	**	**	✓	✓	✓	**
Mid-Age (40-65)	✓✓	**	**	✓	**	**
Average Family Size	**	**	✓	**	✓	**
Lower Density	**	**	**	**	**	**
Score	6	5	6	6	6	4

Chapter 4. Evaluation

4.1. Multi-Attribute Trade-Off Analysis

Multi-attribute trade-off analysis is normally used to select or create rankings of options based on evaluative criteria. In this case I rank the different actions according to six evaluative criteria. Six actions are ranked: retrofitting existing buildings, new buildings, density, mixed-use, transit, and district energy. These actions are evaluated across six criteria: financial impact, intangible impact, emissions reductions, political acceptability, administrative ease and demographic/urban form interaction.

There are at least fourteen different methods of MATA analysis; my approach is adapted from the additive weighting method described by Norris & Marshall (1995). I selected the additive weighting method as it is the best known, most widely used method, and does not require specialized computer software.

Under the additive weighting method, the score for each action is equal to the weighted sum of its ratings for each criteria. The following section outlines the evaluation process.

Step 1. Specify the goal and evaluative criteria

The goal is to rank six actions according to financial impact, intangible impact, emissions reductions, administrative ease, political acceptability, and demographic and density interaction.

Step 2. Identify evaluative criteria ratings

The evaluative criteria ratings have been identified throughout this project. Table 10 lists the evaluative criteria and associated ratings.

Table 10: Evaluative criteria and ratings

Evaluative Criteria	Ratings
Financial Impacts	Negative/Somewhat negative/Somewhat Positive/Positive/Variable
Intangible Impacts	Negative/Somewhat Negative/Somewhat Positive/Positive/Variable
Emissions Reductions	Low/Moderate/Variable/High
Administrative Burden	Low/Moderate/High
Political Acceptability	Low/Moderate/High
Demographic & Density Interactions	Numerical ratings 3 - 10

Step 3. Specify preferences, both for each rating and between the evaluative criteria.

Some ratings are more desirable than others. A high level of political acceptability is more desirable than a low level, for example. To account for this, I assign different preference levels to each rating, starting at 1 for the most desirable rating and declining by 0.25 for each step down in desirability (Table 11).

Table 11: Rating preferences

Financial & Intangible Ratings		Emissions, Administrative, and Political Ratings		Demographic & Density Ratings	
Positive	1	High	1	9-10	1
Somewhat Positive	0.75	Moderate	0.75	7-8	0.75
Somewhat Negative	0.50	Variable	0.50	5-6	0.50
Negative	0.25	Low	0.25	3--4	0.25

Some evaluative criteria may be more important to decision makers than other criteria. For this reason, weights are assigned to the evaluative criteria. I take the weights in Table 12 as an initial basis for the evaluation.

Table 12: Initial Criteria Weights

Rank	Criteria	Weight	Adjusted weight
1	Financial	6	0.29
2	Emissions	5	0.23
3	Administrative	4	0.19
4	Political	3	0.14
5	Intangible	2	0.09
6	Demographic	1	.04
Weight Sum		**21**	**1**

According to the additive weighting method, the final adjusted weights used in the analysis must represent the relative importance of each criteria, and also sum to one. To achieve this, the criteria are ranked in order of importance with the most important criteria given the highest weight and the least important given the lowest weight. The adjusted weights are determined by dividing each criteria's weight by the weight sum (21).

I have listed financial criteria of primary importance, reflecting the fiduciary responsibility of policymakers to ensure they spend public funds wisely, followed by emissions reductions. Administrative feasibility is ranked before political acceptability because an administratively unfeasible action will not go forward, regardless of public support, while with extensive consultation there may be potential to sway public opinion. Intangible and demographic criteria are ranked lowest at first, as they are less certain. Of course, a decision maker can choose an entirely different importance ranking, or assign equal importance to all criteria. I later conduct sensitivity analyses to determine how different rankings may impact results.

The preference levels of the ratings are then multiplied by the associated evaluative criteria weights, and summed across each action.

Step 4. Rank the decision alternatives according to specified preferences.

I rank the action with the highest score first, followed by the second, third, and so on. A full excel spreadsheet of each analysis is available in Appendix B.

4.2. Results

Table 13 lists the initial MATA results. There is very little variation in action rankings, primarily due to placing demographic and density interactions last in importance.

Table 13: MATA ranking results

Rank	Profile 1: Downtown	Profile 2: West	Profile 3: East	Profile 4: Mixed
1	New	New	New	New
2	Existing	Existing	Existing	Existing
3	Density	Density (T)	Density (T)	Density
4	District Energy	District Energy (T)	District Energy (T)	District Energy
5	Mixed-Use	Mixed-Use	Mixed-Use	Mixed-Use
6	Transit	Transit	Transit	Transit

In Table 14 I change the criteria rankings to place demographic and density interactions first to highlight those variations.

Table 14: Revised Criteria Weights

Rank	Criteria	Importance	Weights
1	Demographic	6	0.238
2	Financial	5	0.190
3	Emissions	4	0.142
4	Administrative	3	0.095
5	Political	2	0.047
6	Intangible	1	0.285
Weight Sum		**21**	**1**

Using the revised weights, the results in Table 15 more clearly show the profile variation.

Table 15: Revised ranking results (demographics ranked first)

Rank	Profile 1: Downtown	Profile 2: West	Profile 3: East	Profile 4: Mixed
1	New	New	New	New
2	Density	Existing	Existing	Existing
3	Transit	Mixed	Mixed	Transit
4	Mixed	District Energy	Density	Mixed
5	Existing	Density	District Energy	District Energy
6	District Energy	Transit	Transit	Density

The results show variations in the ranking of actions across the area profiles. The new building action scores high throughout the profiles. Downtown, which is a younger age profile with lower incomes, may be more suited to transit, mixed-use, and density. While the West area, which is an older age profile with higher incomes, may be more suited to mixed-use, retrofitting existing buildings, and new building actions. The East profile may be more suited to retrofits and mixed-use actions. The mixed areas show higher suitability for transit, retrofits, and mixed-use development actions. A lack of demographic preference information regarding district energy and new buildings limits these results as I am unable to capture those variations in the analysis.

The next revised weighting system places equal importance on all evaluative criteria (Table 16). This results in the following rankings:

Table 16: Equal criteria weighting results

Rank	Profile 1: Downtown	Profile 2: West	Profile 3: East	Profile 4: Mixed
1	New	New	New	New
2	Existing	Existing	Existing	Existing
3	Mixed-Use	Mixed-Use	Mixed-Use	Mixed-Use
4	Transit	Density (T)	Transit (T)	Density
5	Density	District Energy (T)	Density (T)	Transit (T)
6	District Energy	Transit	District Energy (T)	District Energy (T)

There is no change in the top three actions between profiles; however, the bottom three (transit, district energy, and density) change to reflect demographic interactions. A (T) indicates a tie in scores between actions.

Finally, in table 17, I remove demographic and intangible values entirely to conduct what may be considered a standard assessment. The weights are as follows:

Table 17: Revised standard weights

Rank	Criteria	Importance	Weights
1	Financial	4	0.4
2	Emissions	3	0.3
3	Admin	2	0.2
4	Political	1	0.1
Weight Sum		**10**	**1**

This results in the following ranking for all four profiles.

Table 18: MATA with 4 evaluative criteria

Rank	Action
1	New
2	Existing
3	Density (T)
4	District Energy (T)
5	Mixed-Use
6	Transit

The importance of the criteria ranking is evident here, as the top four actions all have either somewhat positive or positive financial ratings. Changing the rankings to place emissions reductions first, followed by administrative feasibility, political acceptability and financial impacts last results in new buildings ranked first, followed by density, transit, district energy, retrofitting existing buildings, and mixed-use development. The results do not change substantially if the rankings of financial impacts and emissions are simply switched.

These sensitivity analyses indicate that while there is an impact of adding a demographic/density criterion, the criteria weights may have an even larger impact on action rankings.

Chapter 5. Conclusions and Recommendations

In this research project I reviewed six actions and associated policies to potentially reduce emissions in the built environment against four standard evaluation criteria in addition to intangible values, demographic factors and density factors. The project highlights some of the research gaps in evaluations. I structured the project to critically consider whether some commonly-accepted actions to reduce emissions in the built environment (such as density) are useful in all circumstances. Policymakers should first consider whether certain actions will achieve the results they desire, before identifying appropriate policies to achieve those actions. The results also show the importance of clear identification of weights and sensitivity analyses when conducting MATA's, as the weighting process can have a large impact on results.

5.1. Policy Recommendations for Vancouver

Vancouver is a relatively dense city with a history of progressive environmental policies. Most of the actions analysed here may be suited to many circumstances. However, in some circumstances, certain actions may not be desirable and certain policies may be more effective than others at achieving actions.

New Buildings

Actions for new buildings ranked high through the analysis. These actions were primarily analysed through building regulation policies. Building regulations that encourage new builds to meet stringent standards may reduce emissions in a cost-effective manner with relatively few intangible costs compared to other policy mechanisms. Vancouver already has some of the most stringent new building regulations in Canada and an additional two 'stretch' policies further encourage new building efficiency. However these two policies only target energy savings, not emissions: 1) developers must meet LEED Gold (energy rating) requirements in some rezoning cases, and 2) a Higher Building Policy requires all buildings that exceed current height limits or enter certain view corridors must achieve a 45% reduction in energy consumption as compared to the 2014 Vancouver Building Bylaw. As noted previously, energy reductions can come through efficiency measures or conservation. These may reduce emissions but in some cases, energy can be reduced without significantly reducing emissions. In the case of Vancouver, fuel switching for space and water heating technologies will likely have the most impact on emissions; however, these actions are not specified in building regulations.

Recommendation: *Modify existing building bylaws or create new mandates that specify emissions reductions, not just energy reductions. As the city tightens regulations, care should be taken to ensure intangible costs, particularly to builders, are minimized with adequate consultation and information regarding new regulatory standards. High intangible costs may decrease compliance rates and render the regulatory measures ineffective without high levels of monitoring and enforcement*.

Existing Buildings

Existing buildings also show potential for emissions reductions but are even less regulated than new buildings. Economic incentives such as grants and subsidies may encourage retrofitting, and can be tied specifically to fuel switching actions to target emissions. However, in the city of Vancouver, these programs are offered by third parties that do not always specify the type of investment. Additionally, studies suggest high rates of free-ridership amongst higher income groups for subsidies and grants. While regulations can be used to oblige renovations to meet certain requirements, currently the city structures renovation regulations more as a requirement to consult with an energy advisor, but not a requirement to carry out work. The city has also developed an energy retrofit strategy released in June 2014. However, the strategy report only lists general actions rather than specific policies or methods to cause those actions. For example, the report lists a goal to “support voluntary benchmarking with training” and provide “consultation to develop data sharing” but does not elaborate on how this will be done through either programs or policies (p. 37; Vancouver Energy Retrofit Strategy, 2014).

While there are a number of policies that can support retrofitting actions at the building level, currently the city of Vancouver primarily uses informational policies like consultation, and in the cases of major retrofits, some permit requirements that may trigger consultation requirements or city staff review. The city does not seem to apply its own economic policies and instead relies on third-party incentive programs offered by the provincial government and other organizations.

While a previous pilot project to encourage innovative financing measures in BC was not successful, there is evidence of these programs working both in the United States and other Canadian cities. These measures can help encourage retrofitting actions while minimizing the potential for free ridership.

Recommendation*: Work with provincial government and utilities to pilot innovative options such as property-tax or utility-bill financing. Continue using the Vancouver building bylaw to encourage progressively stronger building regulations, however as with existing buildings, specify emissions reductions, not just energy reductions.*

Density

There are potential intangible costs associated with increasing density and evidence suggesting it may not result in lower emissions. Therefore, I would recommend only using density as a means to achieve ends such as establishing minimum densities to make mixed-use, transit, or district energy cost-effective. Policies should be framed in relation to those three actions, which generally may be more well received by the public and show greater potential to reduce emissions. Policies under a goal to simply increase density may create political opposition related to fears of gentrification, increased crime, noise, and other intangible costs. Density could be encouraged through density bonusing that allows developers greater height allowances or other relaxed standards in exchange for features such as green space, sidewalks, or funding for local community services. Accelerated permitting can fast-track development applications if they provide certain densities or other features that municipalities prefer.

Recommendation*: Only use increased density as a secondary policy to encourage other actions. Economic mechanisms such as density bonusing can increase density while supporting other actions and raising funds for local community infrastructure.*

Mixed-Use Development

Mixed use development seems to be well received by a variety of people and may be cost-effective in large cities such as Vancouver, but it does require minimum densities to ensure developers feel their risks are adequately covered. Policies that encourage mixed-use development are similar to density policies and include zoning, developer tax credits, property taxes, or accelerated permits.

In addition to these strategies, the 2008 British Columbia Local Government Statutes Amendment Act increased the authority of municipal governments to mitigate the environmental effects of development projects by establishing specific development permit areas for promoting energy efficiency, reduced GHG emissions and water conservation. Through this act, local governments such as Vancouver can tie project approvals to specific performance requirements such as density or mixed-use.

Furthermore, existing transit infrastructure in the city of Vancouver gives it wide authority to create zoning for density, mixed-use and district energy systems at those transit nodes. There are still a number of underdeveloped transit nodes throughout the city that can be used to establish mixed-use developments which can later support district energy systems.

Recommendation*: Focus rezoning for mixed-use development particularly near transit nodes.*

Transit

Policy mechanisms that support transit development are primarily regulatory: zoning and planning strategies developed by cities. Economic disincentives to passenger vehicle-use such as vehicle charges, congestion pricing, parking taxes and bridge tolls can also encourage transit use but may experience low political acceptability. Information on scheduling, transit services, and service areas can encourage transit use and may help dispel negative perceptions regarding quality, timing, or speed of services. The city has limited authority to unilaterally increase transit; however, it can improve pedestrian accessibility, walkability, and cycling infrastructure through zoning strategies. In addition, as the majority of Vancouver's emissions come from personal vehicles another strategy to reduce those emissions, besides transit, is to encourage policies that support plug-in hybrid or electric vehicles.

Recommendation*: Continue developing existing transit nodes through rezoning for mixed-use or density and lobby provincial and federal governments for increased action on personal vehicle emissions.*

District Energy

In Vancouver, municipal and provincial government actions support district energy systems. The provincial government amended the Vancouver Charter in 2007 to enable the city to provide energy utility services, after which the city created the Energy Utility System Bylaw to mandate mandatory connection for all new buildings within a development plan area.

District energy has potential to reduce emissions as long as it uses low-carbon fuel sources. The systems themselves can be encouraged through the mandatory connection bylaw, information, and potentially funded through taxes such as the gas tax fund. Related policies that can encourage district energy systems include zoning for mixed-use development or densities that support district energy, technology subsidies, grants to help with connection costs and piping infrastructure, and information campaigns informing developers of system benefits. Additional regulations in the form of bylaws can mandate acceptable fuel sources within city boundaries to ensure emissions are actually reduced.

Recommendation*: Mandate acceptable low-carbon fuel sources for all new district energy development within city boundaries. Tie new major development applications to district energy requirements or bylaws where feasible.*

Some of these recommendations highlight advocacy and lobbying with federal and provincial governments. This is because a large part of city emissions are not under the jurisdictional authority of municipal governments. Without federal and provincial leadership, it will be increasingly difficult for municipalities to meet ambitious climate targets.

5.2. Relevance for other BC communities

While this research project focused mainly on Vancouver, an advantage of highlighting demographic and density interactions is that the findings also have relevance to other BC communities. The city of Vancouver is relatively well suited to undertake most of the actions identified in this study. However, while certain actions and policies are appropriate in Vancouver or even Metro Vancouver, many smaller cities and towns throughout the province are constrained by even less jurisdictional authority, smaller budgets, more dispersed urban forms, and in some cases less progressive political climates.

Many cities and towns in BC are already struggling to fund existing bus systems that at times run almost empty due to low demand. There is a consistent struggle in some communities where a lack of riders limits municipal funds for transit, and a lack of service availability and quality in turn discourages ridership. BC Transit's annual reports from 2012-2013 state that despite the availability of provincial funding for expanded service, only a small number of communities were able to provide their share of required expansion funds. Some communities are forced to raise fares or cut service hours, further discouraging ridership. In cases such as these, plans to expand transit are likely to fail in not just emissions reductions, but in most other evaluative criteria.

Similar problems arise with mixed-use and dense development. High commercial vacancy rates discourage developers from considering mixed-use development in smaller communities, and dense development may be even less preferred by local residents who are accustomed to large backyards, expansive homes, and commuting with personal vehicles.

Regulations for new buildings also face challenges in BC's smaller communities. Some cities may have especially low rates of new construction that render BC's building regulations less effective. Even with high construction rates, municipalities in BC are reliant on provincial leadership. New construction rates in cities such as Kelowna and Kamloops have been high in the last few years; however, these municipalities do not have the same mandates in their charters as Vancouver to enact particularly stringent building regulations. They rely instead on provincial leadership to reduce emissions from their buildings. The provincial government tried to address this in 2008 with the Green Communities Act which gave communities some authority to tie project approvals to energy efficiency or water standards. However, by enacting these mandates communities place themselves at a disadvantage when trying to attract development, which is an existing challenge many smaller communities already face. Communities that unilaterally enact standards may place themselves at a disadvantage when developers are considering multiple cities for investments. Stronger provincial leadership can ensure all communities are subject to the same regulations and help even out the risks of action.

In sum, care should be taken to at least be aware of the broader municipal context actions and policies are implemented within. A solution that works well for Vancouver may not necessarily work well for Prince George, Sechelt, or Nelson. To minimize wasted time and resources, critical analyses can help governments identify the ‘best bang for their buck’ while considering local circumstances.

This study suggests to policymakers that demographic and urban form variation and intangible costs are important to consider when developing policies and selecting actions, particularly across different communities. For policymakers who already have limited resources, time, and information, it may not be feasible to conduct detailed analyses before policy implementation. However, recognition of the unique constraints and preferences communities face when reducing emissions can help make a stronger case for federal and provincial leadership on emissions reductions.

5.3. Limitations

In this research project, I try to provide a transparent and adaptive approach to addressing a complex problem. All of the data sources and rationale are clearly identified throughout the study. This was done to ensure that the impact on the results of any of my subjective judgments can be tested by trying alternative assumptions and assessing their effect. Even with this transparency and flexibility, there are however limitations to the methods and data used.

Data Limitations

Ideally an exercise such as this would not only be conducted at the level of actions, but also policies. Unfortunately, the information required to assess policies for each action with respect to each of the evaluative criteria is not available.

New information would greatly improve the applicability, relevance, and comprehensiveness of the study. In the literature reviews, I tried to use studies from peer-reviewed journals; however, in the case of district energy systems and some building policy evaluations I used government and consulting reports. Similarly, I used consultant and non-profit group surveys for the demographic research. These studies have not been subject to peer-review which would have provided independent scrutiny by other qualified peers to evaluated study methodology, results, and conclusions.

Despite the limitations of the results and methods, the framework of this study illustrates a way to include intangible values, as well as demographic and urban form interactions in action and policy evaluations. It also questions some standard planning literature that encourages certain actions without regard to demographic preferences or existing urban form.

Analysis Limitations

The rating systems that I used relied on judgement and analysis based on a review of available information. For some ratings, I make judgements with relatively little information. Particularly in the case of district energy systems, I relied primarily on two reports. While the reports were from credible sources, more varied sources would better represent different systems and contexts to improve the analysis.

By nature, this research is very broad, which poses challenges in evaluating the quality of the literature sources under review. The study requires analysis and review of a wide range of literature in different disciplines that use different research methods and techniques. In some cases (transportation and spatial modeling techniques, for example), I may not have captured more nuanced factors in my analysis that specialists in these fields would be aware of.

There are limitations with my adaption of multi-attribute trade-off analysis to include the additional factors. The method for the evaluation including demographic and density interactions is original and not based on any previous research. Therefore I was not able to check my results or methods against any similar existing research.

5.4. Future Research

There are a number of future research recommendations that arise from this project. I have organized the recommendations into those that 1) improve data and 2) improve analysis.

Data Improvements

Data quality can be greatly improved by more consistent action and policy evaluation guidelines. Different reporting scopes, units, timescales, and perspectives make comparing results a challenging exercise that necessitates speculation, judgement and greatly increases the margin of error. Improved consistency would help researchers and policymakers make the best decisions possible.

Increasing the number of evaluations is another consideration. There is a lack of monitoring of policies, therefore policymakers and researchers are not always able to determine whether actions or policies did achieve goals, or at what cost goals were achieved. This may be due to limited time, funding, or other resources.

There is very limited quantitative data regarding intangible impacts, though a variety of qualitative data shows that these impacts are likely significant. Improving estimations of intangible impacts can greatly improve policy evaluations. Increased and more comprehensive surveys regarding people's perceptions of policies and actions can improve knowledge of demographic variation. Furthermore. policy evaluations that consider urban form interactions such as building type, mix, or land use can further improve knowledge of how urban form impacts policy effectiveness.

Analysis Improvements

There is also potential to alter the analysis. While in this project I have assumed intangibles to be a separate criterion, it may also be argued that intangible costs could decrease the ability of policies or actions to reduce emissions, thereby informing the criterion of emission reductions rather than existing separately. Intangible costs also have the potential to impact the political acceptability criterion.

Another future research direction could be investigating to what extent demographic interactions are the result of genuine preferences, as opposed to constraints. For example, do people really prefer taking transit or are their options limited by income or other circumstances?

In addition, this study did not consider the potential for intangible impacts to vary over time. There may be value in researching whether preferences for dense development are gradually increasing in certain locations. Or whether, as technology improves over time, intangible costs for certain policies or actions gradually decrease. It is also possible that what appear to be changes in intangible values over time are really changes in demographic characteristics or urban form.

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Appendix A.

Literature Review Data

1. Building Level Intangible Costs

Barrier	Study Location	Method	Impact on Costs	Source
Transaction Costs	Sweden	Empirical Survey	<20.5% and <14.4% of project costs for EE and RE respectively	Krey (2005)
	India	Lit Review	US$ 0.07-0.47/tCO2	UNFCC (2002)
	World	Review project documentatio n	30,000-100,000 Euros per JI/CDM project	UNIDO (2003)
	UK & USA	Bottom-up model	UK: 30% (cavity wall insulation) and 10% (CFLs) of investment costs USA: US$10 (info cost), $5 (vendor info), and $5 (consumer preferences) add to CFL price of $10/piece	Mundaca (2007) Sathaye and Murtishaw (2004)
	World	Interviews	World: <100 E/tCO2 for CDM on EE	Michaelowa and Lotzo (2005)
	UK	Survey	10-20% audit costs for auditing scheme	Mundaca (2007)
	UK	ESCO Interviews	20-40% of project value for ESCSOs	Easton Consultants (1999) non academic
Lack of Understanding	USA	Regression analysis	Energy savings amounted to 10% due to campaign ($130,000/yr)	McMakin et al. (2002)
	USA	Survey	People forewent $5,000 in EE improvements even with assistance	Fowlie (2015)

1b**. Building level intangible benefits**

Benefit	Study Location	Method	Impact	Source
Added Value for EE	Switzerland	Choice Experiment	3% more (insulated façade) 8-13% more (insulated windows)	(Banfi et al., 2008)
	Romania	Hedonic Pricing	2.86% mean added value for retrofitted homes	(Popescu et al., 2012)
Added value for certification	USA	Hedonic Pricing	11.8% selling premium for commercial Energy Star	Fuerst & MacAllister (2008)*
	USA	Hedonic Pricing	9.94% higher selling price for LEED, 5.76% higher for Energy Star	Miller et al., (2008)
Higher quality services			19-43% of saved energy costs	Schweitzer and Tonn, (2002)
Health Benefits (Reduced mortality & morbidity)	Ireland	Bottom-up model	Benefits are 73% of program costs	(J. P. Clinch & Healy, 2003)
Increased comfort from EE (take-back effect)	Ireland	Bottom-up model	Benefits are 29% of program costs	(J. Clinch & Healy, 2001)
Willingness to pay for retrofits	Germany	Survey	Nearly half of households show WTP higher than investment cost	Grosche & Vance (2009)

2a. Site Design Intangible Costs

Costs	Study Location	Method	Impact	Source
Compare costs (commute time) and benefits (larger homes) of sprawl	Los Angeles	Housing Demand Model	WTP: $9.08/yr for extra sq. foot living space, $0.16/yr for extra foot of lot size, $1,403 for increase in structure size, $119 for 10$ increase lot size	Chester?
Preferences for additional storey in house	Australia	Discrete choice model	WTP $103,180 more	Olaru et al. (2011)
Additional m2 in block	Australia	Discrete choice model	WTP $620 more	Olaru et al. (2011)

2b. Site Design Intangible Benefits

Benefit	Study Location	Method	Impact	Source
Added value of mixed-use	NL	Hedonic Pricing	Increase housing values up to 6% for business/leisure	Koster & Rouwendal (2012)
	NL	Hedonic Pricing	Apartment occupiers WTP almost 25% more than those in detached for diversity	Koster & Rouwendal (2012)
	USA (Boston)		Home prices increase by $1,486 for every meter closer to retail uses	Li & Brown (1980)
	USA (Seattle)		Home prices in auto oriented neighbourhoods not affected by retail. In pedestrian neighbourhoods, both + and -	Mathews & Turnball (2007)
Greenspace	Minneapolis		Homes prices increase by .0035% for every % decrease to park, effect increases with proximity to CBD and higher densities	Anderson & West (2006)

Trees	Portland		Street trees within 100 ft of residential property add up to $8,870 in sales price	Donovan & Butry (2010)
Bike paths	Minneapolis		City residents pay more for off-road bike path, suburban residents pay up to $1,058 LESS for locating 400 m closer to path	Krizek (2006)

3a. Node Design Intangible Costs

Cost	Study Location	Method	Impact	Source
Preferences for living in SFD-dominant neighbourhoods	Utah	Discrete Choice experiment	Renters WTP $106 more/month to live in area Homeowners WTP $64,681	Laio (2015)
Heavy Rail	Atlanta	Hedonic Price	Within ¼ mile of transit sell 19% less than those 3+ miles away, those 1-3 miles away sell 3.5% more	Bowes & Ihlanfeldt (2001)

3b. Node Design Intangible Benefits

Benefit	Study Location	Method	Impact	Source
Pedestrian-friendly neighbourhood	Utah	Discrete choice experiment	Renters WTP $134/mnth more to live in area Home owners WTP $35,672 more for home	Laio (2015)
New rail & bus rapid transit	Los Angeles	Life Cycle Assessment	Decreases user costs by $3100/household/yr despite higher rent	Nahlik, (2014)

Move 1 min closer to school	Australia	Discrete choice model	WTP $5,180 more for home	Olaru et al. (2011)
Move 1 min closer to shops	Australia	Discrete choice model	WTP $9,370 more	Olaru et al. (2011)
Move 1 min closer to train station	Australia	Discrete choice model	WTP 3,770 more	Olaru et al. (2011)
Save 10 min travel time/day	Australia	Discrete choice model	WTP 3,250 more	Olaru et al. (2011)
Improved amenity	Australia	Discrete choice model	WTP $70,140 more	Olaru et al. (2011)
Light rail access	USA (16 cities)	Regression	Houses 1 km from transit rent $19 more/mnth sell $4972 more than 3 km from transit	Baum-Snow & Kahn (2000)
Light Rail Access	USA	Hedonic Pricing analysis	Condos ¼ mile away sell $22,000 more and house $12,000 more	Duncan (2008)
Light Rail Access	USA	Hedonic Price	Rents within ¼ mile are 13% higher than those beyond 3.4 mile	Weinberger (2001)
Light Rail Access	USA (Minneapolis)	Hedonic Price	Condos/homes with good access have price premiums of $350 and $45/m of proximity. If separated by arterial and industrial uses show no benefit.	Goetz et al. (2010)
Light Rail/Mixed/Walkability	USA (phoenix)	Hedonic Price	For houses and condos within	Atkinson-Palombo (2010)

			walking distance to transit,those in mixed-use neighborhoods receive premiums of 6 percent and 28 percent, respectively; those in residential-only neighborhoods receive a 12 percent13 percent discount.	
	USA (Chicago)	Hedonic regression	In economically distressed neighborhoods, houses located in traditional neighborhood developments (TND) received a 21 percent 27 percent price discount compared to other infill projects.	Ryan & Weber (2007)
New Urbanist	USA (Portland)	Hedonic	Houses in New Urbanist neighborhoods receive a $24,255 premium compared to houses in convential suburban neighborhoods	Song & Knaap (2003)

Financial Impacts

Barrier	Study Location	Method	Impact	Source
Building – Regulations	Global	Meta-analysis Regs	US$-5 to -189/tCO2 (end user) US$46-$109/tCO2 (social)	Urge-Vorsatz (2009)
	US - BECP	Meta-Review	$400 saved for each $1 spent	Bartlett (2014)

		Regs		
	Europe	Regression Regs	Regulations most effective	O Broin (2015)
	Surrey, BC	Cost/benefit	NPV of 86.86/m2 compared to traditional build	Compass (2008) non academic
	Ireland	Econometric modelling	‘High’ cost effectiveness	Healy (2001)
	US	Metareview	+$.05US (2002) billion	Gillingham (2009)
Building-Economic	UK	Cost/benefit Econ	0.007/kWh adjusted for free riders	Rosenow & Galvin (2013)
	France	Regression Econ	¾ measures cost effective for energy & end users, ¼ for society	Suerkemper (2012)
	UK - CBRP	Cost/benefit	85 E/tCO2, and .03 E/kWh	Mundaca (2007)
	Global	Meta-analysis	0 - US$22/tCO2 (EPC) US$29-$105/tCO2 (subsidies, grants, loans) US$53 to –US$17/tCO2 (public benefit charges)	Urge-Vorsatz (2009)
Building - Information	US	Enhanced billing review	Cost- *,150 million (2008) savings $22,398 million	Erhardt-Marinez (2010)
	Global	Meta analysis	US$-66/tCO2- US$8/tCO2	Urge-Vorsatz (2009)
		Survey	‘Cost-effective’	Murray (2010)
Site - Density	US	Regression	Sprawl 10% more in public service costs, $13,000 per dwelling	Burchell & Mukerjhi
	US	Meta review	40% to 93% of road costs for dispersed 60% to 92% of utility costs 97-102% of school costs	

Node - Transit	US	Meta review	Most not cost effective	Guerra & Cevero
	US	Modelling	Density of 20-75 employees per acre to be cost-effective	Frank & Pivo
Node – Mixed Use	US	Lit review	High planning, construction, design costs	Rabianski (2007)
Node – District Energy	BC		'revenue stream over the life of the investment' however notes ppl can get same return from other investments in efficiency	Ostergaard (2012)
	Global	Modelling	60-400Euros/MWH For feed-in tariffs (low)	Lund (2007)

Energy Impacts

	Study Location	Method	Impact	Source
Building – Regulations	EU	Regression	Statistically significant increase efficiency in ALL 7 countries, increasing over time	Saussay (2012)
	Denmark	Billing	7% actual, 25% expected	Kjaebye (2012)
	Ireland	Billing	10% actual, 20% expected	Rogan & O Gallachoir (2012)
	BC	Audit	10% actual, 5% expected	Deason & Hobbs (2012)
	BC	modelling	3-5% savings	Tiedeman (2002)
	Ireland	Modelling	'High'	Healy (2001

	Global	Meta-analysis	'High'	Urge-Vorsatz (2009
Building-Economic	France	Regression Econ	Significant, but delayed effect	Suerkemper (2012)
	Global	Meta-analysis	'Medium' (subsidies, grants, loans) 'Medium/Low' (public benefit charges)	Urge-Vorsatz (2009)
	Global	Meta analysis	'Medium' – Tax exemptions	Urge-Vorsatz (2009)
Building - information	US	Enhanced billing review	2.5% savings	Erhardt-Marinez (2010)
	US	Before-After regression	Short run effect, doesn't last	Diffney (2013)
	US	Billing review	1.4-3.3% , persisted for two years after	Allcott (2001)
	Sweden	Detailed billing review	.74% reduction, 1.5% increase for control group	Pyrki (2013)
	Austria & Germany		4.5-5% reductions	Schleich (2012)
	US	Detailed billing	No difference for gas	Agnew (2012)
	EU	regression	Ineffective in long term	Broin (2015)
Site - Density	US		1.4 million fewer BTUs than dispersed	Ewing & Rong (2008)
	Toronto		2-2.5 times more efficiency if measured per capita, 1-1.5 times if measured per square footage	Wilson (2011)
	US		SDH 18-20% more fuel energy than MURB	US EIA (1991)

	Finland		High if measured at consumption scope	Heinonen (2012)
	US		Dense resident drive less	Handy (2005)
	US		Link between VMT and density is uncertain, growth in air travel, business travel in centres	Jenks (2000)
	US		Paradox of intensification – increased density increases traffic	Melia (2011)
Node - Transit	US	Life cycle analysis	Reductions up to 470 GgCO2e	Nahlik & chester (2014)
	US	Lit review	High planning, construction, design costs	Rabianski (2007)
Node – Mixed Use			Unknown	
Node – District Energy	BC	Review	Varies based on project fuel source	Ostergaard (2012)

Preferences

	Study Location	Method	Impact	Source
Building –	Sweden	Survey	Under 55 most likely to adopt efficiency measure -36-45 years	Nair (2008)
			Price capitalization of ee highest in older homes, less expensive homes	Cerin (2014)
	US	Survey	Increased household size associated with increased space	Judson & Maller

	US	Survey	Lower income and younger first-time homeowners do not have stronger preferences for density (income constraint)	Dawkins (2009)
	US	Survey	Younger singles prefer dense	(Schoon, 2011;Allen 2004; Mace et al 2007)
	US	Survey Stated Choice	Over 65 willing to forgo size for proximity	Yang (2013)
	US	Survey Stated Choice	Families or those looking to start family prefer lower density areas	Liao (2015) Howley (2009 Winston (2013)
	US	Survey	Preferences for suburban occur among bigger families with high incomes	Liao (2015)
	US	Survey	Once financially able, people relocate to less dense area	Winston (2013)
	US	Survey	Preferred by renters	Winston (2013)

Appendix B.

Multi-Attribute Trade-off Analysis

First MATA

Criteria	Existing	New	Density	Mixed-Use	Transit	District Energy
Financial	SPos	Pos	SPos	Var	Neg	SPos
Emissions	Low	Mod	Var	Low	Mod	Mod
Admin	High	High	Mod	Mod	Low	Mod
Political	High	Mod	Low	Mod	Low	Low
Intangible	Var	SPos	Neg	Var	SPos	Neg
Case 1 Demo	0.25	0.25	0.75	0.75	1	0.25
Case 2 Demo	0.25	0.25	0.25	0.5	0.25	0.25
Case 3 Demo	0.5	0.25	0.25	0.5	0.5	0.25
Case 4 Demo	0.5	0.25	0.5	0.5	0.5	0.25

Utility Values

Criteria	Existing	New	Density	Mixed-Use	Transit	District Energy
Financial	0.75	1	0.75	0.5	0.25	0.75
Emissions	0.25	0.75	0.5	0.25	0.75	0.5
Admin	1	1	0.75	0.75	0.25	0.75
Political	1	0.75	0.25	0.75	0.25	0.25
Intangible	0.5	0.75	0.25	0.5	0.75	0.25
Case 1 Demo	0.25	0.25	0.75	0.75	1	0.25
Case 2 Demo	0.25	0.25	0.25	0.5	0.25	0.25
Case 3 Demo	0.5	0.25	0.25	0.5	0.5	0.25
Case 4 Demo	0.5	0.25	0.5	0.5	0.5	0.25
Case 1 Score	0.666666667	0.845238095	0.571429	0.535714286	0.45238095	0.547619048
Case 2 Score	0.666666667	0.845238095	0.547619	0.523809524	0.41666667	0.547619048
Case 3 Score	0.678571429	0.845238095	0.547619	0.523809524	0.42857143	0.547619048
Case 4 Score	0.678571429	0.845238095	0.559524	0.523809524	0.42857143	0.547619048

Second MATA

Criteria	Existing	New	Density	Mixed-Use	Transit	District Energy
Financial	SPos	Pos	SPos	Var	Neg	SPos
Emissions	Low	Mod	Var	Low	Mod	Mod
Admin	High	High	Mod	Mod	Low	Mod
Political	High	Mod	Low	Mod	Low	Low
Intangible	Var	SPos	Neg	Var	SPos	Neg
Case 1 Demo	0.25	0.25	0.75	0.75	1	0.25
Case 2 Demo	0.25	0.25	0.25	0.5	0.25	0.25
Case 3 Demo	0.5	0.25	0.25	0.5	0.5	0.25
Case 4 Demo	0.5	0.25	0.5	0.5	0.5	0.25

Criteria	Ranking	Weights
Financial	5	0.238095
Emissions	4	0.190476
Admin	3	0.142857
Political	2	0.095238
Intangible	1	0.047619
Demograph	6	0.285714
	21	

Fin/Intang	Positive	1
	Spos	0.75
	Var	0.5
	Neg	0.25
Em/Ad/Pol	High	1
	Mod	0.75
	Variable	0.5
	Low	0.25
Demo/Den	10+	1
	8 to 9	0.75
	6 to 7	0.5
	4 to 5	0.25

Utility Values

Criteria	Existing	New	Density	Mixed-Use	Transit	District Energy
Financial	0.75	1	0.75	0.5	0.25	0.75
Emissions	0.25	0.75	0.5	0.25	0.75	0.5
Admin	1	1	0.75	0.75	0.25	0.75
Political	1	0.75	0.25	0.75	0.25	0.25
Intangible	0.5	0.75	0.25	0.5	0.75	0.25
Case 1 Demo	0.25	0.25	0.75	0.75	1	0.25
Case 2 Demo	0.25	0.25	0.25	0.5	0.25	0.25
Case 3 Demo	0.5	0.25	0.25	0.5	0.5	0.25
Case 4 Demo	0.5	0.25	0.5	0.5	0.5	0.25
Case 1 Score	0.559524	0.702381	0.630952	0.583333	0.583333	0.488095
Case 2 Score	0.559524	0.702381	0.488095	0.511905	0.369048	0.488095
Case 3 Score	0.630952	0.702381	0.488095	0.511905	0.440476	0.488095
Case 4 Score	0.630952	0.702381	0.559524	0.511905	0.440476	0.488095

Third MATA

Criteria	**Existing**	**New**	**Density**	**Mixed-Use**	**Transit**	**District Energy**
Financial	SPos	Pos	SPos	Var	Neg	SPos
Emissions	Low	Mod	Var	Low	Mod	Mod
Admin	High	High	Mod	Mod	Low	Mod
Political	High	Mod	Low	Mod	Low	Low
Intangible	Var	SPos	Neg	Var	SPos	Neg
Case 1 Der	0.25	0.25	0.75	0.75	1	0.25
Case 2 Der	0.25	0.25	0.25	0.5	0.25	0.25
Case 3 Der	0.5	0.25	0.25	0.5	0.5	0.25
Case 4 Der	0.5	0.25	0.5	0.5	0.5	0.25

Criteria	**Ranking**	**Weights**
Financial	6	0.166
Emissions	5	0.166
Admin	4	0.166
Political	3	0.166
Intangible	2	0.166
Demograph	1	0.166
	21	

Fin/Intang	Positive	1
	Spos	0.75
	Var	0.5
	Neg	0.25
Em/Ad/Pol	High	1
	Mod	0.75
	Variable	0.5
	Low	0.25
Demo/Den	10+	1
	8 to 9	0.75
	6 to 7	0.5
	4 to 5	0.25

Utility Values

Criteria	**Existing**	**New**	**Density**	**Mixed-Use**	**Transit**	**District Energy**
Financial	0.75	1	0.75	0.5	0.25	0.75
Emissions	0.25	0.75	0.5	0.25	0.75	0.5
Admin	1	1	0.75	0.75	0.25	0.75
Political	1	0.75	0.25	0.75	0.25	0.25
Intangible	0.5	0.75	0.25	0.5	0.75	0.25
Case 1 Der	0.25	0.25	0.75	0.75	1	0.25
Case 2 Der	0.25	0.25	0.25	0.5	0.25	0.25
Case 3 Der	0.5	0.25	0.25	0.5	0.5	0.25
Case 4 Der	0.5	0.25	0.5	0.5	0.5	0.25
Case 1 Sc	0.6225	0.747	0.5395	0.581	0.5395	0.4565
Case 2 Sc	0.6225	0.747	0.4565	0.5395	0.415	0.4565
Case 3 Sc	0.664	0.747	0.4565	0.5395	0.4565	0.4565
Case 4 Sc	0.664	0.747	0.498	0.5395	0.4565	0.4565

Fourth MATA

Criteria	Existing	New	Density	Mixed-Use	Transit	District Energy
Financial	SPos	Pos	SPos	Var	Neg	SPos
Emissions	Low	Mod	Var	Low	Mod	Mod
Admin	High	High	Mod	Mod	Low	Mod
Political	High	Mod	Low	Mod	Low	Low

Criteria	Ranking	Weights
Financial	1	0.1
Emissions	4	0.4
Admin	3	0.1
Political	2	0.1
		0
		0
	10	

Fin/Intang	Positive	1
	Spos	0.75
	Var	0.5
	Neg	0.25
Em/Ad/Pol	High	1
	Mod	0.75
	Variable	0.5
	Low	0.25
Demo/Den	10+	1
	8 to 9	0.75
	6 to 7	0.5
	4 to 5	0.25

Utility Values

Criteria	Existing	New	Density	Mixed-Use	Transit	District Energy
Financial	0.75	1	0.75	0.5	0.25	0.75
Emissions	0.25	0.75	0.5	0.25	0.75	0.5
Admin	1	1	0.75	0.75	0.25	0.75
Political	1	0.75	0.25	0.75	0.25	0.25

Case 1 Sc	0.375	0.575	0.375	0.3	0.375	0.375
Case 2 Sc	0.375	0.575	0.375	0.3	0.375	0.375
Case 3 Sc	0.375	0.575	0.375	0.3	0.375	0.375
Case 4 Sc	0.375	0.575	0.375	0.3	0.375	0.375