Energy management:
An intervention-based analysis

By

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Author's Declaration

This thesis consists of material all of which I authored or co-authored (as the primary author): see Statement of Contributions included in the thesis. This is a true copy of the thesis, including any required final revisions, as accepted by my examiners.

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Statement of Contributions

The research contained within this thesis was conducted as part of a Social Sciences and Humanities Research Council of Canada (SSHRC) Doctoral Fellowship. The results presented in Chapters 2 to 4 are the basis for manuscripts which are intended to be published in peer-reviewed journals. As a result, a number of co-authors have contributed to the current work. However, all data collection or analysis which were not performed by me were conducted either under my direct supervision, or were coordinated by me. All analysis and synthesis of the results was performed by me. The individual contributions from all co-authors are, in alphabetical order, as follows:

Jeffrey Demaine: co-developed the bibliometric coupling network analysis, and provided editorial feedback in the preparation of Chapter 2.

Bianca Dreyer: co-developed the hierarchical linear model, conducted a subset of the qualitative data collection, and provided technical feedback in the preparation of Chapters 3 and 4.

Alexander Sasha Graham: co-developed the co-citation network analysis, and provided technical feedback in the preparation of Chapter 2.

Prof. Jennifer Lynes: supervised the development of the network analyses, and provided editorial feedback in the preparation of Chapter 2.

Prof John McLevey: developed the reference publication year spectroscopy (RPYS) analysis, and provided technical feedback in the preparation of Chapter 2.

Prof. Manuel Riemer: supervised the development of the hierarchical linear model and the systems model, and provided both technical and editorial feedback in the preparation of Chapters 3 and 4.

Prof. Ian Rowlands: supervised all work completed in this thesis, and provided both technical and editorial feedback in the preparation of Chapter 3.

Abstract

Buildings account for approximately 40% of global energy use and emit 33% of global GHG emissions. Buildings also offer the greatest potential for GHG emission reductions, as energy consumption within existing stock can be reduced by 30-80% using proven and commercially available technologies. Despite this promise, there is a pervasive 'performance gap' between optimal and actual energy use within buildings, even in retrofitted or new high-performance buildings. This gap is attributed to the decision-making of individuals and organizations that occupy buildings and use energy services, resulting in both market and non-market failures. As such, energy efficiency is widely recognized as critical behavioural component that needs to be addressed in climate change mitigation strategy and policy, aimed at reducing the performance gap.

Globally, energy efficiency finance is one of six workstreams under the G20 Energy Efficiency Action Plan, and is seen as an essential component in achieving the United Nations' 7th Sustainable Development Goal (SGD) to "ensure access to affordable, reliable, sustainable, and modern energy for all". Currently, there is an estimated $430 billion USD shortfall in energy efficiency investments to meet this goal; global government and utility spending on energy efficiency was estimated to be US$25.6 billion in 2017, and is expected to grow to US$56.1 billion in 2026.

While the enormous and increasing amounts of taxpayer dollars being spent on energy efficiency around the world are promising, the varying degrees of performance outcomes resulting from these efforts are cause for concern. Examinations of national energy efficiency policies have shown only modest impact on national GHG emissions reductions and that defining energy as a demand-side resource limits the extent to which energy efficiency can be achieved. In addition, spending public funds to reduce negative externalities instead of correcting the internalization of external costs creates asymmetric incentives, leading to heterogeneous results.

Drawing from the pro-environmental behaviour change literature, this dissertation positions stakeholder engagement an integral part of the success of energy efficiency programs, and thus focuses on the energy management decisions of various stakeholders at multiple scales within an energy systems context. Specifically, the relationship between voluntary programs and decisions about electricity consumption – i.e., do the former actually cause the latter to change – is expanded upon in three distinct (but interrelated) papers. The overall goal of this research was to investigate the success factors and barriers to the achievement of GHG emissions reductions in Ontario and to identify potential opportunities to achieve greater energy efficiency and conservation outcomes.

Chapter Two of this dissertation presents a scoping review of the pro-environmental behaviour change literature, with a focus on the important/influential communities of scholarship that shape the structure of the field, and the extent to which emerging research fronts reflect the structural themes. The results revealed that the *Journal of Social Issues* (JSI) 2000 Vol. 56 Issue 3 was a compilation of important/influential papers, measured by co-citation analysis, bibliometric coupling analysis, and four types of centrality. A dense, six-cluster network was revealed, with two papers from this special issue by Stern and Dunlap & Van Liere forming the lobes of the structure. The four themes

identified by the editors of the JSI 2000 special issue – synthesis, motives/values, power, and applicability – were found to generally map onto the structural network. This scoping review also revealed that the emerging research fronts reflect a stronger focus on the applicability of environmental behaviour change theories on salient issues such as consumerism, household (Abrahamse & Steg, 2011) and workplace energy consumption, transportation choice, and tourism.

Chapter Three of this dissertation addresses the identified gap related to consequences of intervention design and implementation through a quantitative analysis of data collected by the Ontario Energy Board (OEB). A multi-level growth curve model was used to explain the achievement and rate of change towards the provincial Peak Demand and Cumulative Energy Savings targets by Ontario's local distribution companies (LDCs) from 2011-2014, the first Conservation First Framework period. While there was insufficient variance in the data to allow for analysis of the Peak Demand target, the model revealed statistically significant variability in the achievement of the Net Cumulative Energy Savings target, as well as the rate of change towards the target amongst the LDCs. The results showed that in the Ontario context, customer density was statistically significant in predicting the achievement of an LDC's Net Cumulative Energy Savings target. More importantly, the statistically significant variance of the rate of change over time demonstrates that LDCs moved towards their respective targets at different rates. This variance was largely left unexplained by the multi-level model developed in this case study, therefore opportunities remain to improve the model and offer further insight into Ontario's energy conservation landscape at this level of the energy system.

Chapter Four of this dissertation focused on the end use of energy, applying systems theory to explore opportunities to reduce the performance gap in commercial office buildings. This study used interview data from Ontario and Alberta, two provinces with different electricity grid compositions, electricity prices, and levels of energy consumption. A conceptual overview of the relationships between system components was developed, and five modes of behaviour were identified as pathways for increasing the investment in building retrofits and stakeholder engagement in energy behaviour programs. In this case study, evidence of collaboration between stakeholders to discuss shared benefits and outcomes created win-win scenarios, and mitigated some of the split-incentive challenges that have been documented in the literature.

Findings from this dissertation contribute to the pro-environmental behaviour change literature by offering quantitative and qualitative evidence that deepen existing knowledge on the design and implementation of interventions to improve energy efficiency outcomes. Collectively, the three distinct papers presented in this dissertation established a need to examine the performance gap through a systems framework in order to ascertain the extent to which impacts at the infrastructure, institutional, and individual levels of the energy system are being addressed, and to leverage opportunities to catalyze motivations and reduce barriers for all system stakeholders, simultaneously. This framework is critical because individuals and organizations do not make decisions about energy efficiency and conservation in isolation; rather they are part of complex and nested social networks, where behaviour is influenced by the interactions and relationships between system components.

Several key conclusions emerged from the synthesis of three papers. Considering electric distribution utilities as the unit of analysis, financial and operational metrics were insufficient at explaining the variability in CDM target achievement and the rate of change towards targets over time, pointing to a need to establish other differences between utilities that may have more predictive power. In the commercial real estate sector, corporate leadership and organizational culture were found to be determinants of retrofit investment behavior, prompting the question of whether such characteristics may also influence CDM target achievement in utilities.

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Producing this thesis has been a test of psychological endurance. I am deeply appreciative of all the people that have contributed to this achievement – too many to acknowledge here, but I will try. First, thank to Ian for challenging me intellectually, sharing my love of spreadsheets and other engineering traits, and for your consistent confidence in my capacity to produce high-quality outputs. I am grateful for your firm commitment to a high standard of quality, and hope that I have made you proud. Your support during the peaks and valleys along my doctoral journey made it possible for me to persevere. Second, thank you to Jenn for convincing me to take a leap of faith, starting me along this path in what feels like another lifetime, and for your encouragement at every step of the process. I would also like to thank Manuel and Mike for your ideas, advice, insights, time and mentorship. Thank you Stephen for your fresh perspective and support of my multi-method, problem-centered approach. I feel lucky to have worked with all of you.

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I am also blessed to be part of several professional and social communities. These groups have enriched my learning and growth, provided motivation, made me feel loved and appreciated, and threw out the life preserver during truly low moments. In no particular order, I offer my sincerest thanks to the Waterloo Institute for Sustainable Energy (WISE, especially Jatin and Iris), the Women in Sustainable Energy Research (WISER) group, the Community, Environment & Justice Research Group (CEJRG, especially Bianca), Chelsie's yoga group, the SERS PhD cohort of 2013, the Sustainable Energy Policy research group, the JAM ladies, my FMM family, and the FHY community.

Looking forward, I am excited to apply my knowledge and experience to making an impact in energy management and the culture of sustainability within commercial office buildings. I also look forward to more community-building through sharing ideas at community meals, clothing swaps and markets, and yoga retreats.

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Chapter 1 – Introduction

1.1 Problem Rationale

Buildings account for approximately 40% of global energy use and emit 33% of global GHG emissions (UNEP, n.d.). Buildings also offer the greatest (and most economically efficient) potential for GHG emission reductions, as energy consumption within existing stock can be reduced by 30 to 80% using proven and commercially available technologies (UNEP, n.d.)[1]. Despite this promise, there is a pervasive 'performance gap' between optimal and actual energy use within buildings (the former being based on technological and economic potential, while the latter is based on market behaviour), even in retrofitted or new high-performance buildings (Allcott & Mullainathan, 2010; Jaffe & Stavins, 1994; Wilson & Dowlatabadi, 2007). This gap is largely attributed to the decision-making of individuals and organizations that occupy buildings and use energy services, resulting in both market and non-market failures (e.g., De Wilde, 2014; Jaffe & Stavins, 1994; Wilson & Dowlatabadi, 2007). In addition, occupant behaviour can undermine the technical measures installed within buildings to save energy (e.g. over-riding thermostat settings) (Lo, Peters, van Breukelen, & Kok, 2014; Sorrell, 2009), but this behaviour "does not negate the benefits of promoting efficiency as climate policy" (Sachs, 2012, p. 1642). As such, energy efficiency and conservation are widely recognized as a critical behavioural components that need to be addressed in climate change mitigation strategy and policy (Lopes, Antunes, & Martins, 2012), aimed at reducing the 'energy efficiency' or 'performance' gap.

Wilson and Dowlatabadi's (2007) definition of an intervention as "any regulation, policy, program, measure, activity, or event that aims to influence behaviour" (p. 170), has been adopted in this paper. While implicit in this definition, it is worth stating explicitly that interventions can result in either voluntary or mandated action, and can be used in any number of ways to achieve desired behaviour change. This research was focused on voluntary behavioural modification as an approach to climate change mitigation, recognizing that other approaches (e.g. building codes and other regulatory instruments that mandate behaviour) are also critical to a low carbon transition (Allcott & Mullainathan, 2010a; Gillingham, Newell, & Palmer, 2006). Given the existing level of technology, encouraging "pro-environmental consumer choice" (Webb, 2012, p.111) is expected to yield significant reductions in carbon emissions, in an economically efficient manner (e.g. Karlin et al., 2015). Even so, this paper argues that the persistence of the performance gap indicates that the complexity of human decision-making and behaviour is insufficiently considered in the current interventions aimed at encouraging pro-environmental consumer choice.

[1] Notably, in McKinsey's (2009) study titled *Pathways to a Low-Carbon Economy: Version 2 of the Global Greenhouse Gas Abatement Cost Curve*, the upfront financial investment of emissions reductions opportunities in the buildings sector is seen as the primary challenge, after which the abatement costs are very low, relative to the suite of available technologies.

1.2 Research Context

Conservation and demand management (CDM) has become common public policy, to reduce electricity consumption and peak electricity demand, and alleviate pressures on generation, transmission, and distribution systems (e.g. Love, 2015; IESO, 2005). Ontario's energy policy is to "invest in conservation first, before new generation, where cost-effective" (MOE, 2013, Minister's message). Under the Conservation First Framework, local distribution companies (LDCs) are provided with long-term funding for CDM programs; $1.8 billion was budgeted for 2011-2014 implementation (OPA, 2014). According to the Ontario Energy Board's 2014 Scorecards – measuring cumulative performance against several metrics – only 7% of Ontario's electricity distributors (5 out of 72) met both of their CDM targets (peak demand and net cumulative savings) (OEB, 2015)[2]. This poor record raises questions about the utility of the province's existing CDM programs, including whether Ontario's 2015-2020 CDM budget of $2.4 billion would be better spent on much-needed infrastructure refurbishment (e.g., Gibbons, 2015). An important overarching question is whether the CDM budget allocation (including the funds devoted to the existing suite of CDM programs) is the most cost-effective way to achieve the desired outcome of reduced peak electricity consumption, and achievement of the provincial GHG emissions reductions targets. Other important questions are why participation in current interventions is lower than anticipated, and how can participation be promoted and encouraged? Given budget constraints and public scrutiny around the spending of public funds, these questions are highly relevant for public policy makers, and for organizations that seek to support energy consumers in implementing energy efficiency and conservation behaviour.

The assumption that individuals are rational (i.e. act primarily in their own self-interest, particularly financial) is rooted in many government policies, including CDM programs. The notion of a boundedly rational individual (Kahneman, 2003) can be appropriate in some contexts. Examples within energy management include modelling consumer preferences for different types of energy technologies and engineering economic analyses, which often successfully predict aggregated sector or market scale choices (Wilson & Dowlatabadi, 2007). On the other hand, evidence has shown that carpooling, water saving, and purchasing of energy efficient goods and services have failed to attain utility maximization, despite the large sums of money spent by governments to encourage these behaviours (e.g., Mckenzie-Mohr, 2000; Welsch & Kühling, 2010). Environmental campaigns often fail to adequately address the influence of habits (frequent behaviour in stable contexts) and social norms (social pressure from knowing that others behave in a certain way, and that others expect a certain behaviour) as strong predictors of behaviour in the design and implementation of interventions (Klöckner, 2013; Thomas & Sharp, 2013). In addition, environmental campaigns often focus on "cognitive judgement about the reality of global warming or the effectiveness of personal choices", instead of the emotional nature of the issue (Coffey & Joseph, 2013, p. 124). The emotional context in which decisions are made can be driven by partisanship and ideological values,

[2] Scorecard compilation by researcher (OEB, the provincial regulator of electricity, provides individual distributor scorecards only). Note: 8% of distributors (6/72) met their peak demand savings target; 57% of distributors (41/72) met their cumulative savings target.

and attachments to these views will change a person's interpretation and response to an intervention (Coffey & Joseph, 2013) and the development of moral norms, or a sense of obligation to compensate for the damage caused by one's behaviour (Bamberg & Möser, 2007). At a minimum, the assumption of rational or boundedly-rational actors is too simplistic to be broadly applied across all contexts in order to achieve pro-environmental behaviours.

Recognizing that stakeholder engagement[3] within CDM programs (as a type of government policy aimed at reducing GHG emissions) is an integral part of the success of these programs, it seems prudent to reflect on how decisions around energy use (made at the individual or organizational levels) are incorporated within a broader view of energy management. The systems perspective, adopted by Karlsson-Vinkhuyzen, Jollands, & Staudt (2012), provides a useful definition of an energy system, which includes:

1. The infrastructure needed to extract, transport, transform and use energy;
2. The physical impacts[4] on the environment and people of energy extraction, transport, transformation and use;
3. The social institutions (such as international agencies, governments and the regulatory frameworks, markets and civil society groups) designed to support the flow of energy services; and
4. The individual actors involved in using energy services, within the system (Karlsson-Vinkhuyzen et al., 2012).

This research focused on energy management decisions, made by either the owners/property managers/operators and/or occupants/tenants within buildings or organizations that use energy services, as per the above definition. Specifically, the relationship between conservation programs (as an intervention, defined, above) and decisions about electricity consumption – i.e., do the former actually cause the latter to change – were investigated in the systems context. This frame is needed because individuals and organizations do not make decisions about consumption in isolation, rather they are part of complex and nested social networks, where behaviour is influenced by the interactions and relationships between actors (or 'nodes' as per the terminology of network theory) (Rogers, 1995; Feick & Price, 1987). The interconnectedness between the four system components will be explicitly discussed, as it is nearly impossible to describe how individuals or organizations make decisions regarding energy use without, at the very least, acknowledging the roles of physical infrastructure and social institutions on these decisions (derived from social practices, e.g. Shove, 2010).

[3] Stakeholder engagement is defined as trust-based collaboration, which integrates stakeholder thinking with ideas from Corporate Social Responsibility (CSR, moral grounds) and strategic thinking (explaining competitive advantage) (Andriof & Waddock, 2002).
[4] The authors cited have adopted the 'public good' framing, where impacts include outcomes such as air pollution.

Given that conservation has been identified as the "cleanest and least costly energy resource" to meet demand (e.g. MOE, 2013), it is not surprising that all customer classes (residential, commercial, and industrial) are the target of interventions from various scales and actors within the energy sector (typically those in governance positions) (e.g., Newsham, Birt, & Rowlands, 2011; Ward, Clark, Jensen, Yen, & Russell, 2011). Interventions are needed because households will generally not partake in energy conservation behaviour on their own volition (e.g., Dütschke & Paetz, 2013). Likewise, organizations require both a strong business case and the correct organizational culture to implement energy conservation measures (e.g., Schelly et al., 2011).

The purpose of this research was to investigate the success factors and barriers to the achievement of GHG emissions reductions in Ontario and Alberta, via energy conservation at various scales and from the perspective of different stakeholders within the energy system, to identify potential opportunities to achieve greater conservation outcomes from the commercial buildings sector. There are innumerable behaviours (at various levels within society) that can result in reduced energy use, and energy conservation is inconsistently defined within the academic and grey literatures on the subject. Drawing on the idea that some degree of individual and societal behaviour change is required to achieve sustainability (e.g., Bruntland, 1987, and others), this research considered the following under the term 'energy conservation': 1) energy efficiency (i.e., reduction in energy use for a given service or level of activity, without affecting the quality of the service or activity), including the uptake of innovative technology (e.g. energy efficient appliances), and 2) changes in social practices surrounding energy use (e.g. expectations about service level and thermal comfort). While load-shifting does not impact the quality of a service or activity, such behaviours were considered as 'energy conservation', since reducing peak use, the infrastructure requirements to meet demand, etc., are desirable outcomes that are embedded in CDM strategies and policies. It is worth explicitly stating that social practices also include the development and maintenance of a 'culture' of conservation, as well as an increased willingness (at both the individual and organizational levels) to 'accept' more regulation or policy in this area. The relevance of these two points will be explored in Chapter 4 of this thesis. Behaviours undertaken for a primary purpose other than energy conservation, but which may have the secondary benefit of reducing energy use, will not be considered (e.g. installation of low-flow showerheads, which are arguably meant to reduce water use, but also reduce energy use, and therefore GHG emissions).

This study included the following specific objectives:

1. To understand and create a network visualization of the current application of pro-environmental behaviour change literature, examining the implications for intervention design and implementation and CDM public policy;
2. To empirically examine Ontario's CDM results (as a case study of intervention design and implementation), specifically, the achievements of the province's local distribution companies (LDCs) with respect to 2011-2014 Peak and Cumulative Demand Targets, as per the Conservation First Framework; and

3. To empirically examine the motivations and barriers of various stakeholders in the commercial buildings sector to engagement in energy management initiatives, including similarities and differences that may arise from various contexts (as a second case study).

The research presented here directly addresses the application of pro-environmental behaviour change theory in the design and implementation of energy conservation interventions, to reveal opportunities to strengthen existing and future interventions in the Canadian landscape. This thesis makes three significant and original contributions to knowledge. First, identifying the most central pieces of pro-environmental behaviour change literature being integrated in intervention design and implementation establishes the extent to which the most current knowledge is being applied, and determines potential gaps to be addressed in future iterations of policy instruments such as the Conservation First Framework. The second contribution is a longitudinal analysis using multi-level modelling of CDM target achievement of Ontario's LDCs during the first CFF timeframe period of 2011-2014. It addresses a gap in knowledge related to the determinants of CDM target achievement, the independent variables related to the Infrastructure and Social Institutions components of the energy system. The third contribution relates to two Canadian geographies, and the motivations and barriers of the major stakeholders in the commercial buildings sector to engage in energy management initiatives. Other scholars have examined the motivations and barriers of individual stakeholders within a system, such as investors in UK that own commercial buildings (Elliott, Bull, & Mallaburn, 2014), however, this is the first undertaking (to the author's knowledge) of investigating the decision-making, opportunities and challenges of the building owners and managers subset of Canada's commercial buildings sector.

This thesis is presented as a collection of three distinct (but interrelated) manuscripts designed to be publishable in academic peer-reviewed journals. Each manuscript contains its own distinct research questions, theoretical grounding, methods, results, analysis and findings. This introductory chapter attempts to nest these three manuscripts within an overarching phenomenon of interest, as per the research objectives and rationale, previously presented. Additional context, literature synthesis, and methodological details are offered to supplement these respective sections (succinctly written) within the manuscripts themselves. The final section in this chapter outlines the organization of this thesis.

1.3 Literature Review

1.3.1 "Wicked" and "super-wicked" problems

It is now widely believed that many of society's problems – issues such as climate change, natural resource management, poverty alleviation, and, ultimately, the pursuit of sustainable development – cannot be fully addressed by one (academic) discipline alone (e.g. Buanes & Jentoft, 2009; Hadorn, Bradley, Pohl, Rist, & Wiesmann, 2006; Lowe, Whitman, & Phillipson, 2009). These issues are coined as wicked, meaning that it is "inherently difficult to define what knowledge is relevant and to determine which solutions are best, and when and if the problem is actually solved" (Buanes & Jentoft, 2009, p. 447); they are global in their scope, ominous in their ability to cross geographical

and temporal scales, and call for unprecedented levels of co-operation between the world's governments, academia, the private sector (which is increasingly multi-national), and broader society, in order to be resolved. The departure from a discipline-specific approach towards an integrated approach to problem-solving has many names and meanings within academic literature, ranging from cross-, multi-, inter-, to transdisciplinary, depending on the degree to which contributions are combined or fused.

Resource consumption and consumerism are "super wicked" problems that "lack simplistic or straightforward planning responses (Rittel and Webber's (1973) conceptualization)" AND for which "time is running out; those who cause the problem also seek to provide a solution; the central authority needed to address them is weak or non-existent; and irrational discounting occurs that pushes responses into the future" (Levin, Cashore, Bernstein, & Auld, 2012, p. 124). Researchers have called for transformative policy work, including analysis of path-dependent (and co-evolutionary) causal processes and routes of stakeholder engagement, in order to adequately address these problems (Howell, 2013; Maréchal, 2009; Ruby, 2015; Shove, 2010). A natural extension of the shift towards cross- to transdisciplinary research, is the use of diverse or mixed methods research (MMR) strategies in studying wicked problems (Mertens, 2015). There is philosophical justification for including both quantitative and qualitative data within the same study; mixed analyses can be considered a distinct methodology (Onwuegbuzie, Johnson, & Collins, 2009). The popularity of MMR has increased over the last few decades; "studies combining qualitative and quantitative research elements are now regularly conducted in several subdomains of the social, behavioral, health, and human sciences" (Heyvaert & Hannes, 2013, p. 302).

This study employs mixed methods in the investigation of the research objectives across the three chapters (see Section 1.5.2), acknowledging the contributions of various disciplinary perspectives to the broader understanding of individual and organizational behaviour. The underlying assumption of this research is that increasing energy conservation behaviours is desirable, and will lead to reduced GHG emissions (see Section 1.3.2). As such, interventions are explored as a pathway to increasing energy conservation behaviours at different scales.

1.3.2 Energy conservation: Its role within the nexus of sustainability

Globally, governance bodies have acknowledged the critical role that sustainable energy production and consumption plays in addressing environmental issues such as climate change (i.e. the measurable, physical impacts, as per the energy systems definition previously presented), as well as socio-economic issues such as national security and equitable energy access (Karlsson-Vinkhuyzen et al., 2012; Wicker & Becken, 2013). Ecological economists have argued that energy should be viewed as a global public good (GPG), in order to facilitate the global governance of energy resources for the welfare of the commons (Karlsson-Vinkhuyzen et al., 2012). Similarly, economic sociologists have conceptualized energy overconsumption as a function of the relationship – embedded with numerous power and political dynamics – among energy infrastructure (i.e. the built environment), social institutions, and individual energy users (parts 2, 3, and 4 of the energy system, as previously presented) (Biggart & Lutzenhiser, 2007). At this meso-level, the relevant "energy

conservation" discourse includes (but is not limited to) the global economic system of trade and commerce (as economic growth is embedded into the design and operation of energy systems) (Karlsson-Vinkhuyzen et al., 2012), social practices and accepted conventions around energy use (Chappells & Shove, 2005; Stephenson et al., 2010), and the "culture" of consumption, more broadly. While I am interested in all of these issues, my research is situated within the meso- and micro-level discourses, specifically, provincial (state) intervention (via policies) to encourage conservation behaviour (energy efficiency and load-shifting) at the individual and firm levels (i.e. demand-side management) (Cuddy, Doherty, & Bos, 2012; Dütschke & Paetz, 2013).

1.3.3 Benefits of energy-efficiency and CDM

CDM provides environmental and social benefits; it is generally agreed upon that energy efficiency and conservation programs are cost effective relative to other methods of supplying electricity. Despite the potential economic, environmental and social benefits, energy efficiency has not 'taken off' (Allcott & Mullainathan, 2010). There are different theories, originating from discipline-specific discourses, as to why this is the case. Economists view poor results as market failure, given their focus on the influence of external conditions, such as income, price, and socio-economic characteristics, upon behavior (Clark, Kotchen, & Moore, 2003; Maréchal, 2009). Psychologists attribute the intervention success (or lack of) to the identification of the correct motivations and barriers to behaviour change (Mckenzie-Mohr, 2000), linking these to value-laden personality traits such as environmental concern (Schultz, 2000). Sociologists frame energy inefficiency as a social problem related to the 'locked-in' wastefulness of physical structures and social practices (Biggart & Lutzenhiser, 2007; Chappells & Shove, 2005; E. Shove, 2012). Furthermore, sociologists posit that policy interventions are erroneously reliant on approaches that are "deeply rooted in conventional economic assumptions and paradigms" (Biggart & Lutzenhiser, 2007, p. 1071). Some social-psychologists argue that the complacency of the general public about the need for transformative behaviour change regarding energy use (as a resource) is more significant than the issue of locked-in inertia. This complacency is posited to result from widespread misunderstanding of basic climate dynamics and the concept of accumulation, leading most people to believe that atmospheric climate change can be "stabilized by stabilizing emissions at or above current rates, and while emissions continuously exceed removal" (Sterman & Sweeney, 2007, p.236). Such erroneous beliefs lead to widespread public support for climate change policies that defer measures that sufficiently stabilize or reduce GHG emissions until substantial economic harm occurs (under the false presumption that climate change can be reversed) (Sterman & Sweeney, 2007). Other social-psychologists see complacency as a coping mechanism for anxiety over death, with severe societal and environmental costs, such as reduced empathy and environmentally destructive behaviour (Arndt, Solomon, Kasser, & Sheldon, 2004; Dickinson, 2009).

Given the highly subsidized nature of energy commodities, homeowners can simply "compromise the expected energy savings in favour of warmer rooms" (Clinch & Healy, 2000, cited in Willand, Ridley, & Maller, 2015, p. 5). Irrationality is further fueled by the emotional value of the "home as a haven" (Green & Gilberston, 2008, cited in Willand et al., 2015) and the "dynamic expression of

household members' feelings" (Wilson, Crane, & Chryssochoidis, 2015, p. 17). Similarly, organizations can simply go on with 'business as usual', passing on opportunities to improve their energy efficiency, particularly if they are not motivated to integrate sustainability into their operations. Motivation can come from external or internal sources such as shareholder expectations, executive leadership or a strong culture of conservation (Gliedt & Hoicka, 2015; Panwar, Nybakk, Pinkse, & Hansen, 2015; Schelly et al., 2011).

1.3.4 Unexploited potential: The `efficiency gap'

As previously described, there is consensus within the literature regarding the persistence of the energy `efficiency gap' – the difference between technological and economic potential of existing technologies, and actual market behaviour (i.e. uptake and use). Jaffe and Stavins (1994) posited that the 'optimal' energy efficiency would balance both economic and social notions, such that appropriate cost-benefit ratios were met, while accurately internalizing the environmental effects of energy generation and use. The barriers to achieving 'optimal' energy efficiency – e.g. imperfect markets, misaligned incentives, limited access to capital, human aversion to risk and uncertainty, organizational barriers (Wilson & Dowlatabadi, 2007) – are so pervasive that the task was, at one time, deemed "surely impossible" (Jaffe & Stavins, 1994, p. 808). Current thinking is less pessimistic, although researchers still consider addressing energy behaviours to be challenging, complex and resource-intensive, involving "intrinsic and inconsistent characteristics" of individuals, and "high variability of energy consumption" between buildings (e.g. Lopes et al., 2012, p. 4012). Interventions are widely accepted as the means to close the energy efficiency gap, at least with respect to addressing barriers that relate to individual decision making (Wilson & Dowlatabadi, 2007).

Empirical studies have shown that CDM (and the associated interventions) can lead to net energy savings, providing that the level of technical improvement can overcome the 'rebound effect' where "increased efficiency decreases the implicit cost of energy services, and consumers respond by increasing quantity demanded" (Bouhou, Blackhurst, & Torres, 2015, p.61). Sorrell et al. (2009) also suggest that regulatory interventions should focus on encouraging dedicated energy-efficiency technologies (e.g. thermal insulation), rather than improving the energy efficiency of `general-purpose' technologies (e.g. electric motors), which generally display much larger rebound effects. My research is premised on empirical evidence from the environmental psychology and energy consumption discourses that show increased energy conservation behaviour as a direct result of intervention (e.g. Allcott, 2010; Bradley, Fudge, & Leach, 2015; Senbel, Ngo, & Blair, 2014).

1.4 Empirical Context

Overall, the Canadian context was selected as an important context to study, given that there are key uncertainties in Canada's energy future, due to growth in export markets and increasing infrastructure demands (National Energy Board, 2014). Specific empirical cases were chosen based on publicly available data sets on the phenomena of interest, geographic convenience, and to take advantage of strong partnership opportunities with industry stakeholders. Two of the nation's most

active provinces with respect to both commercial and industrial activity, as well as energy conservation initiatives, are Ontario and Alberta. The Ontario electricity system offers a unique opportunity to examine the design and implementation of energy conservation interventions, and to glean understanding about the potential implications of the province's complex and highly regulated market (with both public and private sector entities, central management model, and many actors) on conservation efforts. Ontario Power Generation (OPG) is owned by the government of Ontario and produces more than half the province's electricity through nuclear-powered generation plants (Mowat Centre, 2016). Renewable sources of energy also play an increasingly important role in Ontario's energy supply mix, with a political decision to eliminate the province's base supply of coal-fired generation plants, which was accomplished in 2014 (Mowat Centre, 2016). In addition, many of the country's largest private property management firms, including several that are leaders in sustainability, are headquartered in Toronto. The Alberta electricity system is also unique; unlike most provinces in Canada, it is a fully de-regulated market where the Alberta government has never owned or operated any of the utility companies (AESO, 2018). Alberta's electricity mix is supplied largely by coal-fired generation; Alberta produces more coal pollution than all other Canadian provinces combined (Alberta Government, n.d.). Alberta's Climate Leadership Plan includes phasing out all the province's coal-fired generating units by 2030. The nature of the two very different provincial contexts offers a high likelihood for the generalizability of the empirical findings to contexts in regions beyond Canada.

1.4.1 Ontario

Electricity is supplied to Ontario's residents and businesses by one of the approximately 70 local electricity distribution companies (LDCs) that "own and operate the physical infrastructure to convert high-voltage electricity to lower voltage, through transformers, and deliver electricity through distribution lines" (IESO, 2018). Figure 1 lists the major stakeholders in Ontario's electricity system. All of the Hydro One-owned LDCs are included in this analysis. The Independent Electricity System Operator (IESO) manages the power system in real-time, plans for the province's future energy needs, and administers the province's conservation program, assisting in the design and operation of the electricity marketplace, and enabling the evolution of the sector (IESO, 2018).

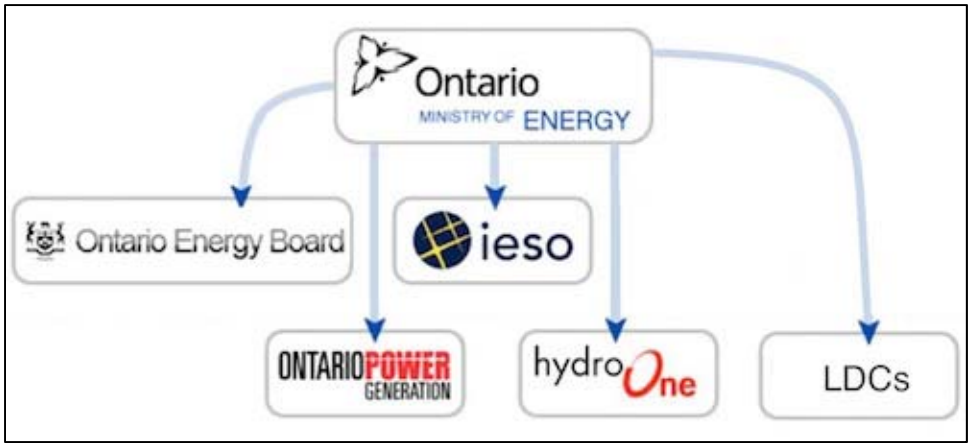

Figure 1: Ontario's Electricity System (Source: IESO, 2018)

1.4.2 Alberta

The power grid in Alberta includes approximately 235 generating units and 200 market participants to the wholesale market (utility owners that own and operate their facilities, but auction the dispatch rights via Power Pool Arrangements (PPA), in accordance with the Electric Utilities Act) (AESO, 2016). The Balancing Pool is a statutory corporation, created by the Government of Alberta to manage the PPA auction proceeds on behalf of consumers, backstopping certain risks inherent in the PPAs, such as rising electricity costs as buyers try to maximize their profits. As part of its Climate Leadership Plan, Alberta is reforming its electricity system, and aims to transition to a capacity market for electricity from the current electricity-only market by 2021 (Alberta Government, n.d.).

The Alberta Electric System Operator (AESO) has parallel responsibilities to Ontario's IESO: it administers the province's competitive capacity market model, operates the Alberta Interconnected Electric System (AIES), implements the Renewable Electricity Program (REP), stewarding the evolution of Alberta's electricity market (AESO, 2016).

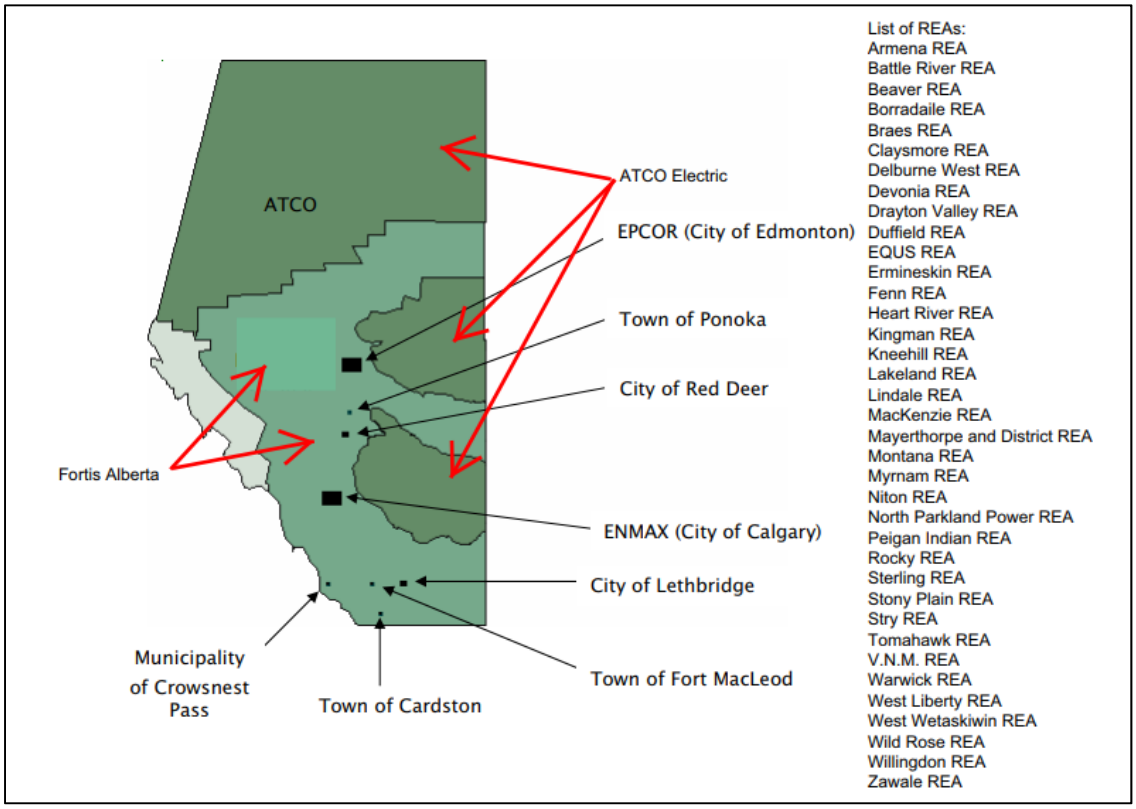

Figure 2: Map of Alberta's electrical wires companies and list of farmer co-ops called Rural Electrification Associations (REAs) (Source: Alberta Utilities Commission and Government of Alberta, 2018)

1.5 Methods

Chapters Two, Three, and Four each contain individual methods sections that are tailored to the goals of the respective manuscripts. This section provides an overarching view of the methodological approach used to achieve the larger study objectives that were presented in Section 1.1. The overall study makes use of both quantitative and qualitative methods, defined by a

pragmatic worldview (Creswell, 2009), in order to allow for the plurality of approaches (across the three chapters) required to address the real-world problems of interest. Pragmatism is an appropriate approach for studying human behaviour, and more specifically, how to encourage voluntary behaviour change around resource consumption, because of the "wicked" nature of the problem, as discussed in Section 1.3.1. The pragmatic approach is problem-centred, and is receptive to the application of "different worldviews, different assumptions, as well as different forms of data collection and analysis… to provide the best understanding of a research problem" (Creswell, 2009; p.11).

A scoping review was first used in Chapter Two to examine the pro-environmental behaviour change literature, with a focus on the important/influential communities of scholarship that shape the structure of the field, and the extent to which emerging research fronts reflect the structural themes. The intent of this examination was to derive insights for the design and implementation of interventions to promote energy efficiency and conservation behaviour, thus bridging behaviour change theory and practice. One clear strength of scoping reviews as a methodology is the shared characteristic of replicability (including transparency of procedure), without the duration of a full systematic review (Grant & Booth, 2009). Scoping reviews can provide preliminary assessment, identifying the nature and the potential of evidence within literature to address phenomena of research interest. Reviews, as a category of methodologies designed to view, inspect, and examine all existing literature through a rigorous and replicable procedure, have been employed in many disciplines of social science research including environmental psychology (e.g., Inoue & Alfaro-Barrantes, 2015; Steg & Vlek, 2009). The desire for evidence-based decision-making has led to an increasing number of systematic reviews (e.g., Staddon et al., 2016) and meta-analyses (e.g., Karlin et al., 2015) conducted in the field of environmental behaviour. This study applies a scoping review protocol that is appropriate for the social scientific study of energy policy, and behaviour in organizations (e.g., Gaede & Rowlands, 2018; Zupic & Čater, 2015). While some qualitative techniques are used to interpret and summarize findings, the analytical approach is primarily quantitative.

Next, two case studies are conducted in order to empirically address the gap identified in the scoping review related to consequences of intervention design and implementation. Case studies facilitate the categorization of information into themes and categories, honing into patterns and proposed generalizations or theories, which can then be compared with existing literature on the topic (Creswell, 2009). The identification of patterns is critical when studying human behaviour because of the role of context in interpreting the root cause(s) (i.e., motivations and barriers) of behaviour (e.g., du Toit & Mouton, 2013; Ruepert et al., 2016; Young et al., 2015), and thus the receptivity to behaviour change interventions (e.g., Azar & Menassa, 2015; Gliedt & Hoicka, 2015; Gregory-Smith, Wells, Manika, & Graham, 2015). In Chapter Three, Ontario's electricity distribution system is examined as a case study on intervention design and implementation. Specifically, a 2-level hierarchical, longitudinal model is developed to explain the achievement of provincial-level conservation and demand management (CDM) targets by the province's local distribution companies

(LDCs). In Chapter Four, a subset of the commercial real estate sector in Ontario and Alberta is examined as a second case study on intervention design and implementation. This case study applied systems theory to qualitatively examine the motivations and barriers for stakeholder engagement in energy management behaviour in order to reduce the performance gap in commercial office buildings.

Data collection and analysis methods are summarized here, and presented in more detail, as appropriate, in Chapters Two, Three, and Four.

1.5.1 Scoping Review of the Pro-environmental Behaviour Change literature

1.5.1.1 Data Collection

Based on a visual inspection of the literature, it appears that scoping reviews, while starting to be published, are less prominent in the literature than other types of reviews. Perhaps this is due to the "largely unacknowledged… subtle variations in the degree of process and rigour within the multifarious review types", as noted by Grant and Booth in their overview of 14 different types of reviews (2009, p.92). According to Arksey and O'Malley (2005) scoping reviews are an appropriate method of identifying gaps in existing literature, and publishing (or otherwise disseminating) research findings, with or without a full systematic review. As scoping reviews do not account for the relative quality of the data, they draw conclusions based solely on characteristics of the literature gathered (Grant and Booth, 2009). Some concerns regarding the quality of findings from scoping reviews can be mitigated by using only peer-reviewed literature from reputable academic databases. A dataset containing a comprehensive representation of the environmental behaviour change literature was compiled using defined inclusion criteria, was used as the data set for this quantitative study (Chapter 2, the first of three manuscripts).

1.5.1.2 Network and Bibliometric Analyses

As academic disciplines grow and mature over time, researchers often seek to understand the evolution of the ideological foundations and influence of seminal publications on the development of the research domain. Given the abundance and accessibility of academic databases, network and bibliometric analyses are increasingly popular methods used by researchers to identify trends and characteristics, influential authors and journals, and the extent of collaboration and interdisciplinary dialogue within their respective fields (Borrett, Moody, & Edelmann, 2014; Gaede & Rowlands, 2018; Gainforth, West, & Michie, 2015; McLevey & McIlroy-Young, 2017).

The relative importance / influence of the articles published in the pro-environmental behaviour change literature was evaluated using a method called Multi Reference Publication Year Spectroscopy (Multi-RPYS) (Marx, Bornmann, Barth, & Leydesdorff, 2014) which is used for identifying years and publications that have been especially important in the historical development of a field.

A co-citation analysis, which draws connections between the cited references based on the times they are cited together by other papers, was conducted for the subset of articles (n=3,224) within the

pro-environmental behaviour literature, namely the citations of the *Journal of Social Issues* (JSI) 2000 Volume 56 Issue 3 special issue. Extraction and analysis of the citation network (i.e., the network structure consisting of papers that influenced the structure of the field) was performed using *metaknowledge*, a Python package developed by McLevey & McIlroy-Young (2017) specifically for computational research in information science, network analysis, and history of science. The Louvain community detection algorithm (Blondel, Guillaume, Lambiotte, & Lefebvre, 2008) was used to derive the network structure, with the number of co-citations (edges) between papers (nodes) set to three (3).

A bibliometric coupling analysis, which draws connections between papers based on the number of times they cite the same publications, was conducted for the same special issue. Extraction and analysis of the coupling network (i.e., the network structure consisting of emerging research in the field) was performed using Sci2. The Louvain community detection algorithm (Blondel et al., 2008), was used to derive the network structure, with the number of bibliographic couplings (edges) between papers (nodes) set to 10.

For both the co-citation and bibliographic coupling, the network visualization was completed in Gephi Version 0.9.2.

1.5.2 Quantitative Analysis of Electricity Distributors' Performance Data

1.5.2.1 Data Collection

The Ontario Energy Board (OEB) is the province's independent energy regulator, whose full- and part-time Board members, executive management team, and supporting staff make decisions and rules to ensure that consumers are treated fairly and that the energy sector is reliable and sustainable. The OEB oversees how energy companies operate to ensure the public interest is served. Board members are appointed by the Lieutenant Governor in Council (OEB, 2018). As part of its mandate to encourage higher performance from natural gas and electricity utilities and to measure progress, the OEB compiles and makes publicly available an annual *Yearbook of Electricity Distributors*, which reports financial and operational data on all of Ontario's LDCs.

The annual publication of the Yearbook data provided an opportunity to ascertain whether there are correlations between any number of independent variables related to traditional operating performance (e.g. debt-to-equity ratio, costs) at the LDC-level, and achievement of the energy conservation targets, set by the OEB. While the OEB measures and reports on the performance of Ontario's energy distributors annually, they do not provide analysis to accompany these traditional metrics. Thus, the performance data cannot offer insight as to why LDCs may or may not have achieved their CDM targets, only if the targets were met. Ascertaining the extent to which target achievement was correlated to specific measures of operating performance may improve the efficiency and effectiveness of CDM planning and implementation by energy distributors, leading to greater achievement of Ontario's Conservation Framework goals and objectives. The Yearbook data, from 2011-2014, were used as the data set for this quantitative study (Chapter 3, the second of three manuscripts).

1.5.2.2 Hierarchical Linear Modelling

The primary objective of statistical analysis is to develop mathematical models that can plausibly explain observed data (historical) about a phenomenon, in order to draw meaningful and useful conclusions, including predictions or forecasts about the topic being studied (Field, 2005; Shumway & Stoffer, 2016). Statistical models represent real-world processes or phenomena, attempting to explain how these processes or phenomena operate under a set of conditions (Field, 2005), using only the information from a set of observations to forecast future values (Judge et al., 1988).

People exist within many hierarchical organizational structures, simultaneously – families, schools, business organizations, churches, towns, states, and countries, to name a few; hierarchies also exist within these structures, such as employees within production or skill units, businesses, and economic industrial sectors (J. W. Osborne, 2000). Another type of hierarchical data is individual change over time (e.g., growth or decay), where data are collected for an individual at multiple points in time (Raudenbush & Bryk, 2002).

Hierarchical Linear Modelling (HLM) is an appropriate tool to analyze the CDM performance of Ontario's LDCs, because the performance of any given LDC over the course of the Conservation First Framework time period is best represented by a growth curve. This is the case for any indicators of cumulative performance over time, since values for each LDC can never be lower than the prior year. As such, variance in the growth curve model is restricted within each LDC and across LDCs. HLM has many advantages when analyzing this type of nested data, including the accommodation of cumulative data (Raudenbush & Bryk, 2002). In addition, using HLM allows for simultaneous modelling of both the achievement of the CDM target each year and the rate of change toward the target over time. Using another statistical method such as multiple linear regression would require separate models for each year, which would then be combined.

A 2-level hierarchical, longitudinal, slopes-as-outcomes model with random coefficients was used to explain the achievement of the CDM targets by individual LDCs.

1.5.3 Qualitative analysis of Commercial Real Estate Sector

1.5.3.1 Data Collection

It is a widely recognized premise that "high-quality interviews are the linchpin of success for virtually all qualitative studies" (Padgett, 2012, p. 123). Data for this study (Chapter 4, last of three manuscripts) were obtained through semi-structured interviews, review of relevant documents, and personal observations[5] between March and June 2017. As with other studies that have sought to explore participants' experiences in energy conservation interventions (e.g., Bradley, Fudge, & Leach, 2015; Dumitru et al., 2016; Hope & Booth, 2014), interviews were chosen as the data collection method to gain insight about the participants' social constructs and understand their motivations and barriers for engaging in energy management initiatives. A set of 43 interviews with

[5] During the semi-structured interviews, personal observations of temperament, overall interest in the discussion topics, and emphasis of specific ideas, words and phrases were noted. These observations were capture in reflection memos periodically throughout the interview process.

corporate executives, sustainability directors, property managers, operators, and tenants in senior decision-making positions was used as the data set for this qualitative study.

Based on a literature review, the context or unique circumstances that shape events, actions, and meaning for the stakeholders (Maxwell, 1996) in which stakeholders operate was deductively conceptualized (Creswell, 2009) – four broad themes were hypothesized to influence energy management practices in commercial buildings: Built Environment, Leadership Context, Stakeholder Engagement, and External Drivers. These themes, illustrated in Figure 3, were used as a framework for exploring the research questions and developing the interview protocol.

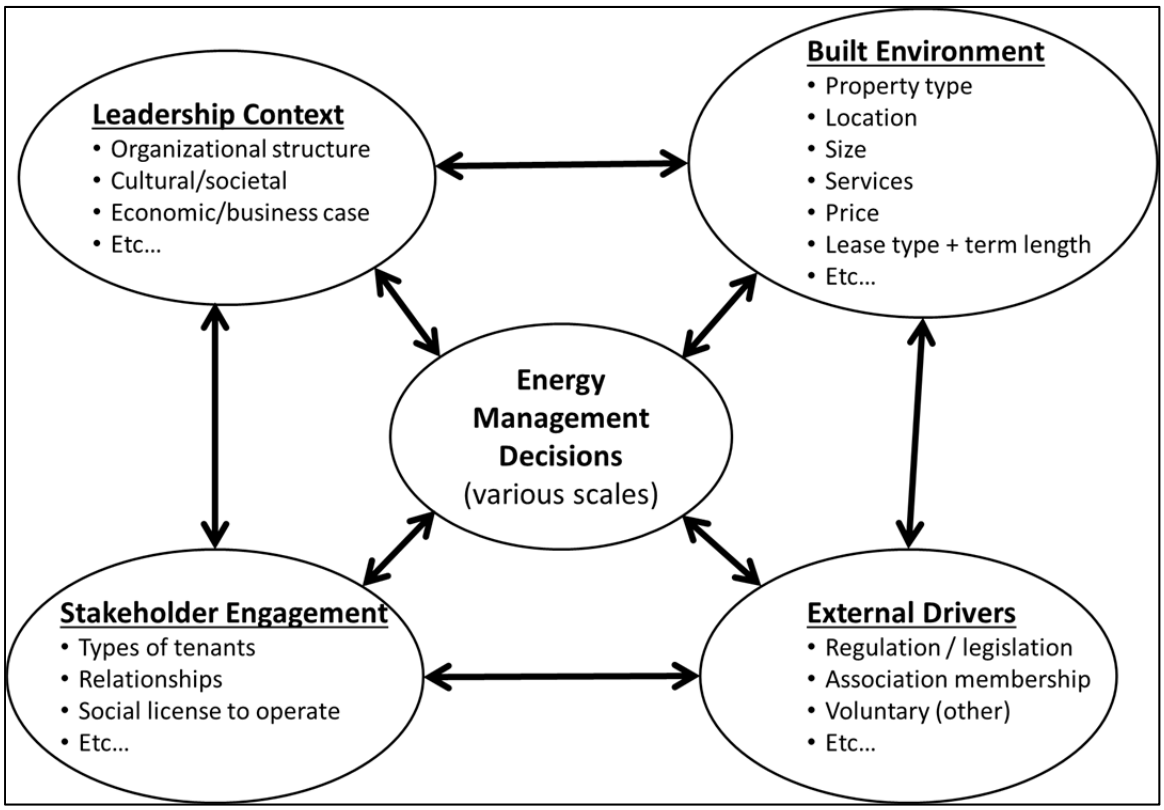

Figure 3: Initial conceptual framework, based on literature review

1.5.3.2 Open and Axial Coding

An inductive approach to data analysis was used, allowing meaning to be constructed by the interview participants (Creswell, 2009). The transcripts generated from the interviews were interpreted using 'open' and 'axial' coding, conducted in Dedoose (version 8.0.36), a web-based software application for qualitative and quantitative data management and analysis. Open coding was used to apply conceptual labels or codes to the data, based on the participants' own words (Robson, 2002). Axial coding was then used to categorize the open codes, and the data were further explored for relationships between the categories, including themes and patterns (Robson, 2002). After one round of open and axial coding, the resulting codebook was compared to the deductive conceptual framework based on the literature. It was determined that two levels of codes fit well

Chapter 1 – Introduction

1.1 Problem Rationale

Buildings account for approximately 40% of global energy use and emit 33% of global GHG emissions (UNEP, n.d.). Buildings also offer the greatest (and most economically efficient) potential for GHG emission reductions, as energy consumption within existing stock can be reduced by 30 to 80% using proven and commercially available technologies (UNEP, n.d.)[1]. Despite this promise, there is a pervasive 'performance gap' between optimal and actual energy use within buildings (the former being based on technological and economic potential, while the latter is based on market behaviour), even in retrofitted or new high-performance buildings (Allcott & Mullainathan, 2010; Jaffe & Stavins, 1994; Wilson & Dowlatabadi, 2007). This gap is largely attributed to the decision-making of individuals and organizations that occupy buildings and use energy services, resulting in both market and non-market failures (e.g., De Wilde, 2014; Jaffe & Stavins, 1994; Wilson & Dowlatabadi, 2007). In addition, occupant behaviour can undermine the technical measures installed within buildings to save energy (e.g. over-riding thermostat settings) (Lo, Peters, van Breukelen, & Kok, 2014; Sorrell, 2009), but this behaviour "does not negate the benefits of promoting efficiency as climate policy" (Sachs, 2012, p. 1642). As such, energy efficiency and conservation are widely recognized as a critical behavioural components that need to be addressed in climate change mitigation strategy and policy (Lopes, Antunes, & Martins, 2012), aimed at reducing the 'energy efficiency' or 'performance' gap.

Wilson and Dowlatabadi's (2007) definition of an intervention as "any regulation, policy, program, measure, activity, or event that aims to influence behaviour" (p. 170), has been adopted in this paper. While implicit in this definition, it is worth stating explicitly that interventions can result in either voluntary or mandated action, and can be used in any number of ways to achieve desired behaviour change. This research was focused on voluntary behavioural modification as an approach to climate change mitigation, recognizing that other approaches (e.g. building codes and other regulatory instruments that mandate behaviour) are also critical to a low carbon transition (Allcott & Mullainathan, 2010a; Gillingham, Newell, & Palmer, 2006). Given the existing level of technology, encouraging "pro-environmental consumer choice" (Webb, 2012, p.111) is expected to yield significant reductions in carbon emissions, in an economically efficient manner (e.g. Karlin et al., 2015). Even so, this paper argues that the persistence of the performance gap indicates that the complexity of human decision-making and behaviour is insufficiently considered in the current interventions aimed at encouraging pro-environmental consumer choice.

[1] Notably, in McKinsey's (2009) study titled *Pathways to a Low-Carbon Economy: Version 2 of the Global Greenhouse Gas Abatement Cost Curve*, the upfront financial investment of emissions reductions opportunities in the buildings sector is seen as the primary challenge, after which the abatement costs are very low, relative to the suite of available technologies.

1.2 Research Context

Conservation and demand management (CDM) has become common public policy, to reduce electricity consumption and peak electricity demand, and alleviate pressures on generation, transmission, and distribution systems (e.g. Love, 2015; IESO, 2005). Ontario's energy policy is to "invest in conservation first, before new generation, where cost-effective" (MOE, 2013, Minister's message). Under the Conservation First Framework, local distribution companies (LDCs) are provided with long-term funding for CDM programs; $1.8 billion was budgeted for 2011-2014 implementation (OPA, 2014). According to the Ontario Energy Board's 2014 Scorecards – measuring cumulative performance against several metrics – only 7% of Ontario's electricity distributors (5 out of 72) met both of their CDM targets (peak demand and net cumulative savings) (OEB, 2015)[2]. This poor record raises questions about the utility of the province's existing CDM programs, including whether Ontario's 2015-2020 CDM budget of $2.4 billion would be better spent on much-needed infrastructure refurbishment (e.g., Gibbons, 2015). An important overarching question is whether the CDM budget allocation (including the funds devoted to the existing suite of CDM programs) is the most cost-effective way to achieve the desired outcome of reduced peak electricity consumption, and achievement of the provincial GHG emissions reductions targets. Other important questions are why participation in current interventions is lower than anticipated, and how can participation be promoted and encouraged? Given budget constraints and public scrutiny around the spending of public funds, these questions are highly relevant for public policy makers, and for organizations that seek to support energy consumers in implementing energy efficiency and conservation behaviour.

The assumption that individuals are rational (i.e. act primarily in their own self-interest, particularly financial) is rooted in many government policies, including CDM programs. The notion of a boundedly rational individual (Kahneman, 2003) can be appropriate in some contexts. Examples within energy management include modelling consumer preferences for different types of energy technologies and engineering economic analyses, which often successfully predict aggregated sector or market scale choices (Wilson & Dowlatabadi, 2007). On the other hand, evidence has shown that carpooling, water saving, and purchasing of energy efficient goods and services have failed to attain utility maximization, despite the large sums of money spent by governments to encourage these behaviours (e.g., Mckenzie-Mohr, 2000; Welsch & Kühling, 2010). Environmental campaigns often fail to adequately address the influence of habits (frequent behaviour in stable contexts) and social norms (social pressure from knowing that others behave in a certain way, and that others expect a certain behaviour) as strong predictors of behaviour in the design and implementation of interventions (Klöckner, 2013; Thomas & Sharp, 2013). In addition, environmental campaigns often focus on "cognitive judgement about the reality of global warming or the effectiveness of personal choices", instead of the emotional nature of the issue (Coffey & Joseph, 2013, p. 124). The emotional context in which decisions are made can be driven by partisanship and ideological values,

[2] Scorecard compilation by researcher (OEB, the provincial regulator of electricity, provides individual distributor scorecards only). Note: 8% of distributors (6/72) met their peak demand savings target; 57% of distributors (41/72) met their cumulative savings target.

and attachments to these views will change a person's interpretation and response to an intervention (Coffey & Joseph, 2013) and the development of moral norms, or a sense of obligation to compensate for the damage caused by one's behaviour (Bamberg & Möser, 2007). At a minimum, the assumption of rational or boundedly-rational actors is too simplistic to be broadly applied across all contexts in order to achieve pro-environmental behaviours.

Recognizing that stakeholder engagement[3] within CDM programs (as a type of government policy aimed at reducing GHG emissions) is an integral part of the success of these programs, it seems prudent to reflect on how decisions around energy use (made at the individual or organizational levels) are incorporated within a broader view of energy management. The systems perspective, adopted by Karlsson-Vinkhuyzen, Jollands, & Staudt (2012), provides a useful definition of an energy system, which includes:

1. The infrastructure needed to extract, transport, transform and use energy;
2. The physical impacts[4] on the environment and people of energy extraction, transport, transformation and use;
3. The social institutions (such as international agencies, governments and the regulatory frameworks, markets and civil society groups) designed to support the flow of energy services; and
4. The individual actors involved in using energy services, within the system (Karlsson-Vinkhuyzen et al., 2012).

This research focused on energy management decisions, made by either the owners/property managers/operators and/or occupants/tenants within buildings or organizations that use energy services, as per the above definition. Specifically, the relationship between conservation programs (as an intervention, defined, above) and decisions about electricity consumption – i.e., do the former actually cause the latter to change – were investigated in the systems context. This frame is needed because individuals and organizations do not make decisions about consumption in isolation, rather they are part of complex and nested social networks, where behaviour is influenced by the interactions and relationships between actors (or 'nodes' as per the terminology of network theory) (Rogers, 1995; Feick & Price, 1987). The interconnectedness between the four system components will be explicitly discussed, as it is nearly impossible to describe how individuals or organizations make decisions regarding energy use without, at the very least, acknowledging the roles of physical infrastructure and social institutions on these decisions (derived from social practices, e.g. Shove, 2010).

[3] Stakeholder engagement is defined as trust-based collaboration, which integrates stakeholder thinking with ideas from Corporate Social Responsibility (CSR, moral grounds) and strategic thinking (explaining competitive advantage) (Andriof & Waddock, 2002).
[4] The authors cited have adopted the 'public good' framing, where impacts include outcomes such as air pollution.

Given that conservation has been identified as the "cleanest and least costly energy resource" to meet demand (e.g. MOE, 2013), it is not surprising that all customer classes (residential, commercial, and industrial) are the target of interventions from various scales and actors within the energy sector (typically those in governance positions) (e.g., Newsham, Birt, & Rowlands, 2011; Ward, Clark, Jensen, Yen, & Russell, 2011). Interventions are needed because households will generally not partake in energy conservation behaviour on their own volition (e.g., Dütschke & Paetz, 2013). Likewise, organizations require both a strong business case and the correct organizational culture to implement energy conservation measures (e.g., Schelly et al., 2011).

The purpose of this research was to investigate the success factors and barriers to the achievement of GHG emissions reductions in Ontario and Alberta, via energy conservation at various scales and from the perspective of different stakeholders within the energy system, to identify potential opportunities to achieve greater conservation outcomes from the commercial buildings sector. There are innumerable behaviours (at various levels within society) that can result in reduced energy use, and energy conservation is inconsistently defined within the academic and grey literatures on the subject. Drawing on the idea that some degree of individual and societal behaviour change is required to achieve sustainability (e.g., Bruntland, 1987, and others), this research considered the following under the term 'energy conservation': 1) energy efficiency (i.e., reduction in energy use for a given service or level of activity, without affecting the quality of the service or activity), including the uptake of innovative technology (e.g. energy efficient appliances), and 2) changes in social practices surrounding energy use (e.g. expectations about service level and thermal comfort). While load-shifting does not impact the quality of a service or activity, such behaviours were considered as 'energy conservation', since reducing peak use, the infrastructure requirements to meet demand, etc., are desirable outcomes that are embedded in CDM strategies and policies. It is worth explicitly stating that social practices also include the development and maintenance of a 'culture' of conservation, as well as an increased willingness (at both the individual and organizational levels) to 'accept' more regulation or policy in this area. The relevance of these two points will be explored in Chapter 4 of this thesis. Behaviours undertaken for a primary purpose other than energy conservation, but which may have the secondary benefit of reducing energy use, will not be considered (e.g. installation of low-flow showerheads, which are arguably meant to reduce water use, but also reduce energy use, and therefore GHG emissions).

This study included the following specific objectives:

1. To understand and create a network visualization of the current application of pro-environmental behaviour change literature, examining the implications for intervention design and implementation and CDM public policy;
2. To empirically examine Ontario's CDM results (as a case study of intervention design and implementation), specifically, the achievements of the province's local distribution companies (LDCs) with respect to 2011-2014 Peak and Cumulative Demand Targets, as per the Conservation First Framework; and

3. To empirically examine the motivations and barriers of various stakeholders in the commercial buildings sector to engagement in energy management initiatives, including similarities and differences that may arise from various contexts (as a second case study).

The research presented here directly addresses the application of pro-environmental behaviour change theory in the design and implementation of energy conservation interventions, to reveal opportunities to strengthen existing and future interventions in the Canadian landscape. This thesis makes three significant and original contributions to knowledge. First, identifying the most central pieces of pro-environmental behaviour change literature being integrated in intervention design and implementation establishes the extent to which the most current knowledge is being applied, and determines potential gaps to be addressed in future iterations of policy instruments such as the Conservation First Framework. The second contribution is a longitudinal analysis using multi-level modelling of CDM target achievement of Ontario's LDCs during the first CFF timeframe period of 2011-2014. It addresses a gap in knowledge related to the determinants of CDM target achievement, the independent variables related to the Infrastructure and Social Institutions components of the energy system. The third contribution relates to two Canadian geographies, and the motivations and barriers of the major stakeholders in the commercial buildings sector to engage in energy management initiatives. Other scholars have examined the motivations and barriers of individual stakeholders within a system, such as investors in UK that own commercial buildings (Elliott, Bull, & Mallaburn, 2014), however, this is the first undertaking (to the author's knowledge) of investigating the decision-making, opportunities and challenges of the building owners and managers subset of Canada's commercial buildings sector.

This thesis is presented as a collection of three distinct (but interrelated) manuscripts designed to be publishable in academic peer-reviewed journals. Each manuscript contains its own distinct research questions, theoretical grounding, methods, results, analysis and findings. This introductory chapter attempts to nest these three manuscripts within an overarching phenomenon of interest, as per the research objectives and rationale, previously presented. Additional context, literature synthesis, and methodological details are offered to supplement these respective sections (succinctly written) within the manuscripts themselves. The final section in this chapter outlines the organization of this thesis.

1.3 Literature Review

1.3.1 "Wicked" and "super-wicked" problems

It is now widely believed that many of society's problems – issues such as climate change, natural resource management, poverty alleviation, and, ultimately, the pursuit of sustainable development – cannot be fully addressed by one (academic) discipline alone (e.g. Buanes & Jentoft, 2009; Hadorn, Bradley, Pohl, Rist, & Wiesmann, 2006; Lowe, Whitman, & Phillipson, 2009). These issues are coined as wicked, meaning that it is "inherently difficult to define what knowledge is relevant and to determine which solutions are best, and when and if the problem is actually solved" (Buanes & Jentoft, 2009, p. 447); they are global in their scope, ominous in their ability to cross geographical

and temporal scales, and call for unprecedented levels of co-operation between the world's governments, academia, the private sector (which is increasingly multi-national), and broader society, in order to be resolved. The departure from a discipline-specific approach towards an integrated approach to problem-solving has many names and meanings within academic literature, ranging from cross-, multi-, inter-, to transdisciplinary, depending on the degree to which contributions are combined or fused.

Resource consumption and consumerism are "super wicked" problems that "lack simplistic or straightforward planning responses (Rittel and Webber's (1973) conceptualization)" AND for which "time is running out; those who cause the problem also seek to provide a solution; the central authority needed to address them is weak or non-existent; and irrational discounting occurs that pushes responses into the future" (Levin, Cashore, Bernstein, & Auld, 2012, p. 124). Researchers have called for transformative policy work, including analysis of path-dependent (and co-evolutionary) causal processes and routes of stakeholder engagement, in order to adequately address these problems (Howell, 2013; Maréchal, 2009; Ruby, 2015; Shove, 2010). A natural extension of the shift towards cross- to transdisciplinary research, is the use of diverse or mixed methods research (MMR) strategies in studying wicked problems (Mertens, 2015). There is philosophical justification for including both quantitative and qualitative data within the same study; mixed analyses can be considered a distinct methodology (Onwuegbuzie, Johnson, & Collins, 2009). The popularity of MMR has increased over the last few decades; "studies combining qualitative and quantitative research elements are now regularly conducted in several subdomains of the social, behavioral, health, and human sciences" (Heyvaert & Hannes, 2013, p. 302).

This study employs mixed methods in the investigation of the research objectives across the three chapters (see Section 1.5.2), acknowledging the contributions of various disciplinary perspectives to the broader understanding of individual and organizational behaviour. The underlying assumption of this research is that increasing energy conservation behaviours is desirable, and will lead to reduced GHG emissions (see Section 1.3.2). As such, interventions are explored as a pathway to increasing energy conservation behaviours at different scales.

1.3.2 Energy conservation: Its role within the nexus of sustainability

Globally, governance bodies have acknowledged the critical role that sustainable energy production and consumption plays in addressing environmental issues such as climate change (i.e. the measurable, physical impacts, as per the energy systems definition previously presented), as well as socio-economic issues such as national security and equitable energy access (Karlsson-Vinkhuyzen et al., 2012; Wicker & Becken, 2013). Ecological economists have argued that energy should be viewed as a global public good (GPG), in order to facilitate the global governance of energy resources for the welfare of the commons (Karlsson-Vinkhuyzen et al., 2012). Similarly, economic sociologists have conceptualized energy overconsumption as a function of the relationship – embedded with numerous power and political dynamics – among energy infrastructure (i.e. the built environment), social institutions, and individual energy users (parts 2, 3, and 4 of the energy system, as previously presented) (Biggart & Lutzenhiser, 2007). At this meso-level, the relevant "energy

conservation" discourse includes (but is not limited to) the global economic system of trade and commerce (as economic growth is embedded into the design and operation of energy systems) (Karlsson-Vinkhuyzen et al., 2012), social practices and accepted conventions around energy use (Chappells & Shove, 2005; Stephenson et al., 2010), and the "culture" of consumption, more broadly. While I am interested in all of these issues, my research is situated within the meso- and micro-level discourses, specifically, provincial (state) intervention (via policies) to encourage conservation behaviour (energy efficiency and load-shifting) at the individual and firm levels (i.e. demand-side management) (Cuddy, Doherty, & Bos, 2012; Dütschke & Paetz, 2013).

1.3.3 Benefits of energy-efficiency and CDM

CDM provides environmental and social benefits; it is generally agreed upon that energy efficiency and conservation programs are cost effective relative to other methods of supplying electricity. Despite the potential economic, environmental and social benefits, energy efficiency has not 'taken off' (Allcott & Mullainathan, 2010). There are different theories, originating from discipline-specific discourses, as to why this is the case. Economists view poor results as market failure, given their focus on the influence of external conditions, such as income, price, and socio-economic characteristics, upon behavior (Clark, Kotchen, & Moore, 2003; Maréchal, 2009). Psychologists attribute the intervention success (or lack of) to the identification of the correct motivations and barriers to behaviour change (Mckenzie-Mohr, 2000), linking these to value-laden personality traits such as environmental concern (Schultz, 2000). Sociologists frame energy inefficiency as a social problem related to the 'locked-in' wastefulness of physical structures and social practices (Biggart & Lutzenhiser, 2007; Chappells & Shove, 2005; E. Shove, 2012). Furthermore, sociologists posit that policy interventions are erroneously reliant on approaches that are "deeply rooted in conventional economic assumptions and paradigms" (Biggart & Lutzenhiser, 2007, p. 1071). Some social-psychologists argue that the complacency of the general public about the need for transformative behaviour change regarding energy use (as a resource) is more significant than the issue of locked-in inertia. This complacency is posited to result from widespread misunderstanding of basic climate dynamics and the concept of accumulation, leading most people to believe that atmospheric climate change can be "stabilized by stabilizing emissions at or above current rates, and while emissions continuously exceed removal" (Sterman & Sweeney, 2007, p.236). Such erroneous beliefs lead to widespread public support for climate change policies that defer measures that sufficiently stabilize or reduce GHG emissions until substantial economic harm occurs (under the false presumption that climate change can be reversed) (Sterman & Sweeney, 2007). Other social-psychologists see complacency as a coping mechanism for anxiety over death, with severe societal and environmental costs, such as reduced empathy and environmentally destructive behaviour (Arndt, Solomon, Kasser, & Sheldon, 2004; Dickinson, 2009).

Given the highly subsidized nature of energy commodities, homeowners can simply "compromise the expected energy savings in favour of warmer rooms" (Clinch & Healy, 2000, cited in Willand, Ridley, & Maller, 2015, p. 5). Irrationality is further fueled by the emotional value of the "home as a haven" (Green & Gilberston, 2008, cited in Willand et al., 2015) and the "dynamic expression of

household members' feelings" (Wilson, Crane, & Chryssochoidis, 2015, p. 17). Similarly, organizations can simply go on with 'business as usual', passing on opportunities to improve their energy efficiency, particularly if they are not motivated to integrate sustainability into their operations. Motivation can come from external or internal sources such as shareholder expectations, executive leadership or a strong culture of conservation (Gliedt & Hoicka, 2015; Panwar, Nybakk, Pinkse, & Hansen, 2015; Schelly et al., 2011).

1.3.4 Unexploited potential: The `efficiency gap'

As previously described, there is consensus within the literature regarding the persistence of the energy `efficiency gap' – the difference between technological and economic potential of existing technologies, and actual market behaviour (i.e. uptake and use). Jaffe and Stavins (1994) posited that the 'optimal' energy efficiency would balance both economic and social notions, such that appropriate cost-benefit ratios were met, while accurately internalizing the environmental effects of energy generation and use. The barriers to achieving 'optimal' energy efficiency – e.g. imperfect markets, misaligned incentives, limited access to capital, human aversion to risk and uncertainty, organizational barriers (Wilson & Dowlatabadi, 2007) – are so pervasive that the task was, at one time, deemed "surely impossible" (Jaffe & Stavins, 1994, p. 808). Current thinking is less pessimistic, although researchers still consider addressing energy behaviours to be challenging, complex and resource-intensive, involving "intrinsic and inconsistent characteristics" of individuals, and "high variability of energy consumption" between buildings (e.g. Lopes et al., 2012, p. 4012). Interventions are widely accepted as the means to close the energy efficiency gap, at least with respect to addressing barriers that relate to individual decision making (Wilson & Dowlatabadi, 2007).

Empirical studies have shown that CDM (and the associated interventions) can lead to net energy savings, providing that the level of technical improvement can overcome the 'rebound effect' where "increased efficiency decreases the implicit cost of energy services, and consumers respond by increasing quantity demanded" (Bouhou, Blackhurst, & Torres, 2015, p.61). Sorrell et al. (2009) also suggest that regulatory interventions should focus on encouraging dedicated energy-efficiency technologies (e.g. thermal insulation), rather than improving the energy efficiency of `general-purpose' technologies (e.g. electric motors), which generally display much larger rebound effects. My research is premised on empirical evidence from the environmental psychology and energy consumption discourses that show increased energy conservation behaviour as a direct result of intervention (e.g. Allcott, 2010; Bradley, Fudge, & Leach, 2015; Senbel, Ngo, & Blair, 2014).

1.4 Empirical Context

Overall, the Canadian context was selected as an important context to study, given that there are key uncertainties in Canada's energy future, due to growth in export markets and increasing infrastructure demands (National Energy Board, 2014). Specific empirical cases were chosen based on publicly available data sets on the phenomena of interest, geographic convenience, and to take advantage of strong partnership opportunities with industry stakeholders. Two of the nation's most

active provinces with respect to both commercial and industrial activity, as well as energy conservation initiatives, are Ontario and Alberta. The Ontario electricity system offers a unique opportunity to examine the design and implementation of energy conservation interventions, and to glean understanding about the potential implications of the province's complex and highly regulated market (with both public and private sector entities, central management model, and many actors) on conservation efforts. Ontario Power Generation (OPG) is owned by the government of Ontario and produces more than half the province's electricity through nuclear-powered generation plants (Mowat Centre, 2016). Renewable sources of energy also play an increasingly important role in Ontario's energy supply mix, with a political decision to eliminate the province's base supply of coal-fired generation plants, which was accomplished in 2014 (Mowat Centre, 2016). In addition, many of the country's largest private property management firms, including several that are leaders in sustainability, are headquartered in Toronto. The Alberta electricity system is also unique; unlike most provinces in Canada, it is a fully de-regulated market where the Alberta government has never owned or operated any of the utility companies (AESO, 2018). Alberta's electricity mix is supplied largely by coal-fired generation; Alberta produces more coal pollution than all other Canadian provinces combined (Alberta Government, n.d.). Alberta's Climate Leadership Plan includes phasing out all the province's coal-fired generating units by 2030. The nature of the two very different provincial contexts offers a high likelihood for the generalizability of the empirical findings to contexts in regions beyond Canada.

1.4.1 Ontario

Electricity is supplied to Ontario's residents and businesses by one of the approximately 70 local electricity distribution companies (LDCs) that "own and operate the physical infrastructure to convert high-voltage electricity to lower voltage, through transformers, and deliver electricity through distribution lines" (IESO, 2018). Figure 1 lists the major stakeholders in Ontario's electricity system. All of the Hydro One-owned LDCs are included in this analysis. The Independent Electricity System Operator (IESO) manages the power system in real-time, plans for the province's future energy needs, and administers the province's conservation program, assisting in the design and operation of the electricity marketplace, and enabling the evolution of the sector (IESO, 2018).

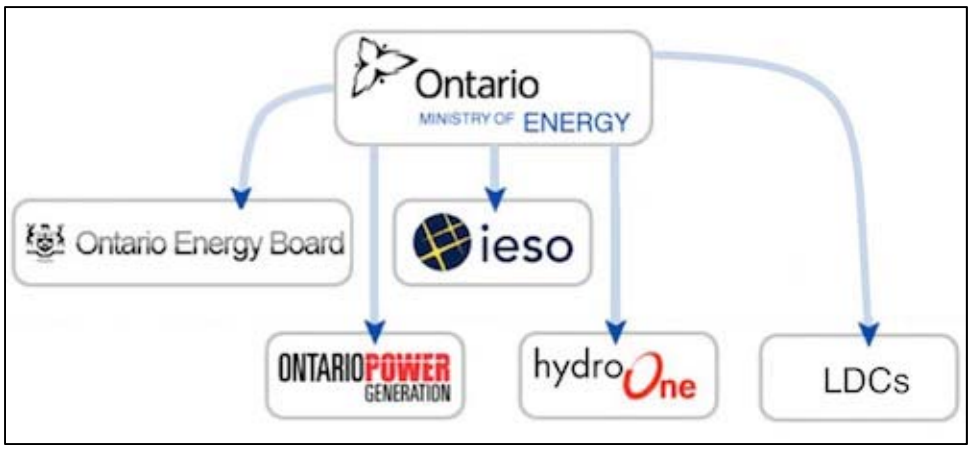

Figure 1: Ontario's Electricity System (Source: IESO, 2018)

1.4.2 Alberta

The power grid in Alberta includes approximately 235 generating units and 200 market participants to the wholesale market (utility owners that own and operate their facilities, but auction the dispatch rights via Power Pool Arrangements (PPA), in accordance with the Electric Utilities Act) (AESO, 2016). The Balancing Pool is a statutory corporation, created by the Government of Alberta to manage the PPA auction proceeds on behalf of consumers, backstopping certain risks inherent in the PPAs, such as rising electricity costs as buyers try to maximize their profits. As part of its Climate Leadership Plan, Alberta is reforming its electricity system, and aims to transition to a capacity market for electricity from the current electricity-only market by 2021 (Alberta Government, n.d.).

The Alberta Electric System Operator (AESO) has parallel responsibilities to Ontario's IESO: it administers the province's competitive capacity market model, operates the Alberta Interconnected Electric System (AIES), implements the Renewable Electricity Program (REP), stewarding the evolution of Alberta's electricity market (AESO, 2016).

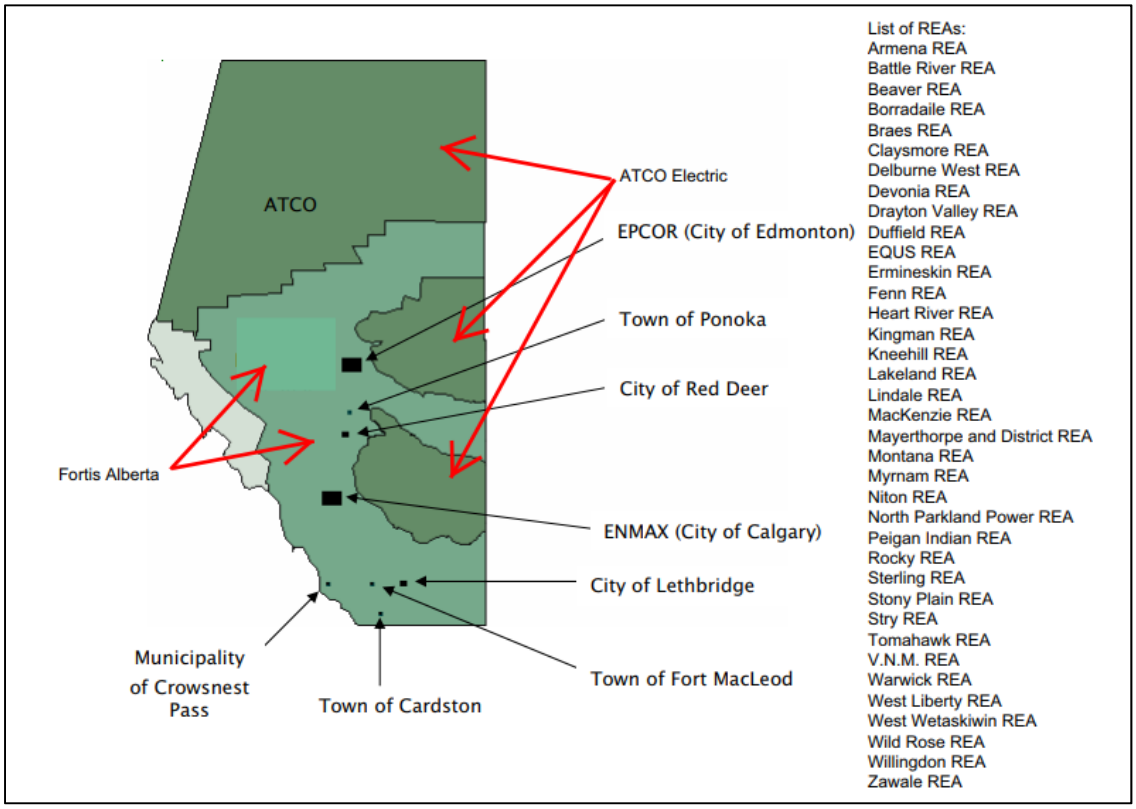

Figure 2: Map of Alberta's electrical wires companies and list of farmer co-ops called Rural Electrification Associations (REAs) (Source: Alberta Utilities Commission and Government of Alberta, 2018)

1.5 Methods

Chapters Two, Three, and Four each contain individual methods sections that are tailored to the goals of the respective manuscripts. This section provides an overarching view of the methodological approach used to achieve the larger study objectives that were presented in Section 1.1. The overall study makes use of both quantitative and qualitative methods, defined by a

pragmatic worldview (Creswell, 2009), in order to allow for the plurality of approaches (across the three chapters) required to address the real-world problems of interest. Pragmatism is an appropriate approach for studying human behaviour, and more specifically, how to encourage voluntary behaviour change around resource consumption, because of the "wicked" nature of the problem, as discussed in Section 1.3.1. The pragmatic approach is problem-centred, and is receptive to the application of "different worldviews, different assumptions, as well as different forms of data collection and analysis… to provide the best understanding of a research problem" (Creswell, 2009; p.11).

A scoping review was first used in Chapter Two to examine the pro-environmental behaviour change literature, with a focus on the important/influential communities of scholarship that shape the structure of the field, and the extent to which emerging research fronts reflect the structural themes. The intent of this examination was to derive insights for the design and implementation of interventions to promote energy efficiency and conservation behaviour, thus bridging behaviour change theory and practice. One clear strength of scoping reviews as a methodology is the shared characteristic of replicability (including transparency of procedure), without the duration of a full systematic review (Grant & Booth, 2009). Scoping reviews can provide preliminary assessment, identifying the nature and the potential of evidence within literature to address phenomena of research interest. Reviews, as a category of methodologies designed to view, inspect, and examine all existing literature through a rigorous and replicable procedure, have been employed in many disciplines of social science research including environmental psychology (e.g., Inoue & Alfaro-Barrantes, 2015; Steg & Vlek, 2009). The desire for evidence-based decision-making has led to an increasing number of systematic reviews (e.g., Staddon et al., 2016) and meta-analyses (e.g., Karlin et al., 2015) conducted in the field of environmental behaviour. This study applies a scoping review protocol that is appropriate for the social scientific study of energy policy, and behaviour in organizations (e.g., Gaede & Rowlands, 2018; Zupic & Čater, 2015). While some qualitative techniques are used to interpret and summarize findings, the analytical approach is primarily quantitative.

Next, two case studies are conducted in order to empirically address the gap identified in the scoping review related to consequences of intervention design and implementation. Case studies facilitate the categorization of information into themes and categories, honing into patterns and proposed generalizations or theories, which can then be compared with existing literature on the topic (Creswell, 2009). The identification of patterns is critical when studying human behaviour because of the role of context in interpreting the root cause(s) (i.e., motivations and barriers) of behaviour (e.g., du Toit & Mouton, 2013; Ruepert et al., 2016; Young et al., 2015), and thus the receptivity to behaviour change interventions (e.g., Azar & Menassa, 2015; Gliedt & Hoicka, 2015; Gregory-Smith, Wells, Manika, & Graham, 2015). In Chapter Three, Ontario's electricity distribution system is examined as a case study on intervention design and implementation. Specifically, a 2-level hierarchical, longitudinal model is developed to explain the achievement of provincial-level conservation and demand management (CDM) targets by the province's local distribution companies

(LDCs). In Chapter Four, a subset of the commercial real estate sector in Ontario and Alberta is examined as a second case study on intervention design and implementation. This case study applied systems theory to qualitatively examine the motivations and barriers for stakeholder engagement in energy management behaviour in order to reduce the performance gap in commercial office buildings.

Data collection and analysis methods are summarized here, and presented in more detail, as appropriate, in Chapters Two, Three, and Four.

1.5.1 Scoping Review of the Pro-environmental Behaviour Change literature

1.5.1.1 Data Collection

Based on a visual inspection of the literature, it appears that scoping reviews, while starting to be published, are less prominent in the literature than other types of reviews. Perhaps this is due to the "largely unacknowledged… subtle variations in the degree of process and rigour within the multifarious review types", as noted by Grant and Booth in their overview of 14 different types of reviews (2009, p.92). According to Arksey and O'Malley (2005) scoping reviews are an appropriate method of identifying gaps in existing literature, and publishing (or otherwise disseminating) research findings, with or without a full systematic review. As scoping reviews do not account for the relative quality of the data, they draw conclusions based solely on characteristics of the literature gathered (Grant and Booth, 2009). Some concerns regarding the quality of findings from scoping reviews can be mitigated by using only peer-reviewed literature from reputable academic databases. A dataset containing a comprehensive representation of the environmental behaviour change literature was compiled using defined inclusion criteria, was used as the data set for this quantitative study (Chapter 2, the first of three manuscripts).

1.5.1.2 Network and Bibliometric Analyses

As academic disciplines grow and mature over time, researchers often seek to understand the evolution of the ideological foundations and influence of seminal publications on the development of the research domain. Given the abundance and accessibility of academic databases, network and bibliometric analyses are increasingly popular methods used by researchers to identify trends and characteristics, influential authors and journals, and the extent of collaboration and interdisciplinary dialogue within their respective fields (Borrett, Moody, & Edelmann, 2014; Gaede & Rowlands, 2018; Gainforth, West, & Michie, 2015; McLevey & McIlroy-Young, 2017).

The relative importance / influence of the articles published in the pro-environmental behaviour change literature was evaluated using a method called Multi Reference Publication Year Spectroscopy (Multi-RPYS) (Marx, Bornmann, Barth, & Leydesdorff, 2014) which is used for identifying years and publications that have been especially important in the historical development of a field.

A co-citation analysis, which draws connections between the cited references based on the times they are cited together by other papers, was conducted for the subset of articles (n=3,224) within the

pro-environmental behaviour literature, namely the citations of the *Journal of Social Issues* (JSI) 2000 Volume 56 Issue 3 special issue. Extraction and analysis of the citation network (i.e., the network structure consisting of papers that influenced the structure of the field) was performed using *metaknowledge*, a Python package developed by McLevey & McIlroy-Young (2017) specifically for computational research in information science, network analysis, and history of science. The Louvain community detection algorithm (Blondel, Guillaume, Lambiotte, & Lefebvre, 2008) was used to derive the network structure, with the number of co-citations (edges) between papers (nodes) set to three (3).

A bibliometric coupling analysis, which draws connections between papers based on the number of times they cite the same publications, was conducted for the same special issue. Extraction and analysis of the coupling network (i.e., the network structure consisting of emerging research in the field) was performed using Sci2. The Louvain community detection algorithm (Blondel et al., 2008), was used to derive the network structure, with the number of bibliographic couplings (edges) between papers (nodes) set to 10.

For both the co-citation and bibliographic coupling, the network visualization was completed in Gephi Version 0.9.2.

1.5.2 Quantitative Analysis of Electricity Distributors' Performance Data

1.5.2.1 Data Collection

The Ontario Energy Board (OEB) is the province's independent energy regulator, whose full- and part-time Board members, executive management team, and supporting staff make decisions and rules to ensure that consumers are treated fairly and that the energy sector is reliable and sustainable. The OEB oversees how energy companies operate to ensure the public interest is served. Board members are appointed by the Lieutenant Governor in Council (OEB, 2018). As part of its mandate to encourage higher performance from natural gas and electricity utilities and to measure progress, the OEB compiles and makes publicly available an annual *Yearbook of Electricity Distributors*, which reports financial and operational data on all of Ontario's LDCs.

The annual publication of the Yearbook data provided an opportunity to ascertain whether there are correlations between any number of independent variables related to traditional operating performance (e.g. debt-to-equity ratio, costs) at the LDC-level, and achievement of the energy conservation targets, set by the OEB. While the OEB measures and reports on the performance of Ontario's energy distributors annually, they do not provide analysis to accompany these traditional metrics. Thus, the performance data cannot offer insight as to why LDCs may or may not have achieved their CDM targets, only if the targets were met. Ascertaining the extent to which target achievement was correlated to specific measures of operating performance may improve the efficiency and effectiveness of CDM planning and implementation by energy distributors, leading to greater achievement of Ontario's Conservation Framework goals and objectives. The Yearbook data, from 2011-2014, were used as the data set for this quantitative study (Chapter 3, the second of three manuscripts).

1.5.2.2 Hierarchical Linear Modelling

The primary objective of statistical analysis is to develop mathematical models that can plausibly explain observed data (historical) about a phenomenon, in order to draw meaningful and useful conclusions, including predictions or forecasts about the topic being studied (Field, 2005; Shumway & Stoffer, 2016). Statistical models represent real-world processes or phenomena, attempting to explain how these processes or phenomena operate under a set of conditions (Field, 2005), using only the information from a set of observations to forecast future values (Judge et al., 1988).

People exist within many hierarchical organizational structures, simultaneously – families, schools, business organizations, churches, towns, states, and countries, to name a few; hierarchies also exist within these structures, such as employees within production or skill units, businesses, and economic industrial sectors (J. W. Osborne, 2000). Another type of hierarchical data is individual change over time (e.g., growth or decay), where data are collected for an individual at multiple points in time (Raudenbush & Bryk, 2002).

Hierarchical Linear Modelling (HLM) is an appropriate tool to analyze the CDM performance of Ontario's LDCs, because the performance of any given LDC over the course of the Conservation First Framework time period is best represented by a growth curve. This is the case for any indicators of cumulative performance over time, since values for each LDC can never be lower than the prior year. As such, variance in the growth curve model is restricted within each LDC and across LDCs. HLM has many advantages when analyzing this type of nested data, including the accommodation of cumulative data (Raudenbush & Bryk, 2002). In addition, using HLM allows for simultaneous modelling of both the achievement of the CDM target each year and the rate of change toward the target over time. Using another statistical method such as multiple linear regression would require separate models for each year, which would then be combined.

A 2-level hierarchical, longitudinal, slopes-as-outcomes model with random coefficients was used to explain the achievement of the CDM targets by individual LDCs.

1.5.3 Qualitative analysis of Commercial Real Estate Sector

1.5.3.1 Data Collection

It is a widely recognized premise that "high-quality interviews are the linchpin of success for virtually all qualitative studies" (Padgett, 2012, p. 123). Data for this study (Chapter 4, last of three manuscripts) were obtained through semi-structured interviews, review of relevant documents, and personal observations[5] between March and June 2017. As with other studies that have sought to explore participants' experiences in energy conservation interventions (e.g., Bradley, Fudge, & Leach, 2015; Dumitru et al., 2016; Hope & Booth, 2014), interviews were chosen as the data collection method to gain insight about the participants' social constructs and understand their motivations and barriers for engaging in energy management initiatives. A set of 43 interviews with

[5] During the semi-structured interviews, personal observations of temperament, overall interest in the discussion topics, and emphasis of specific ideas, words and phrases were noted. These observations were capture in reflection memos periodically throughout the interview process.

corporate executives, sustainability directors, property managers, operators, and tenants in senior decision-making positions was used as the data set for this qualitative study.

Based on a literature review, the context or unique circumstances that shape events, actions, and meaning for the stakeholders (Maxwell, 1996) in which stakeholders operate was deductively conceptualized (Creswell, 2009) – four broad themes were hypothesized to influence energy management practices in commercial buildings: Built Environment, Leadership Context, Stakeholder Engagement, and External Drivers. These themes, illustrated in Figure 3, were used as a framework for exploring the research questions and developing the interview protocol.

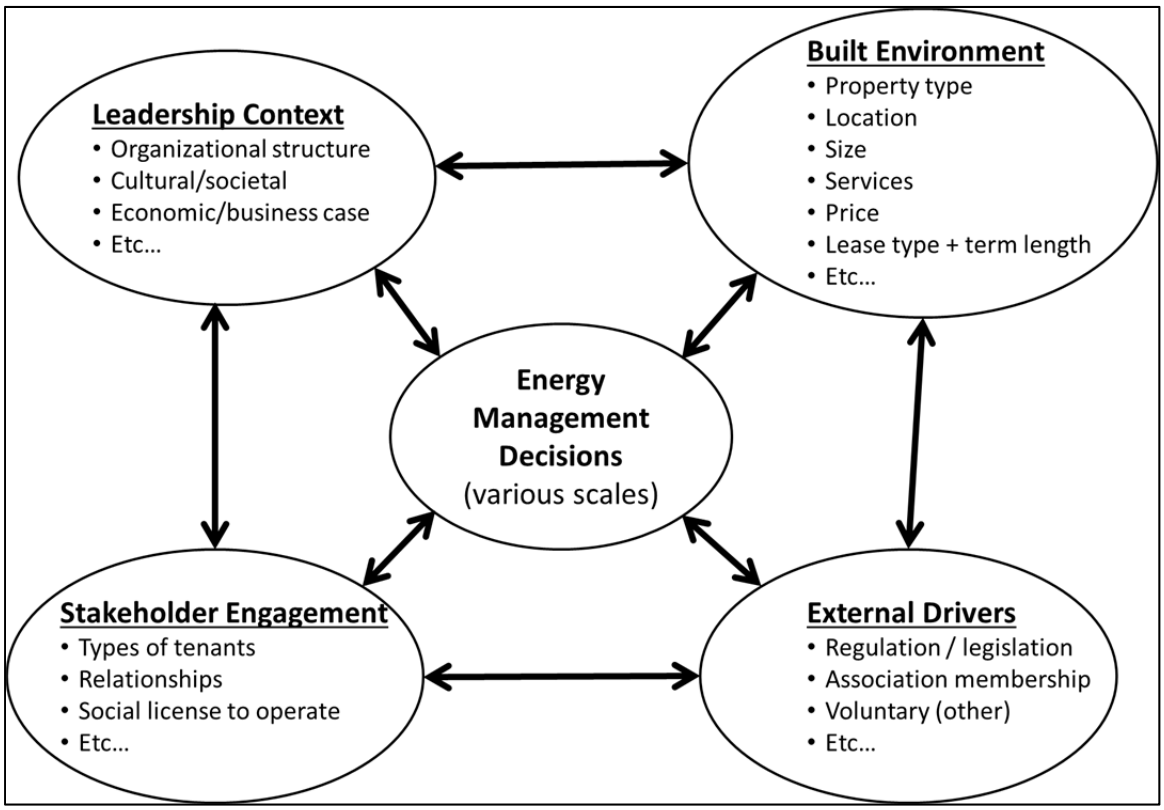

Figure 3: Initial conceptual framework, based on literature review

1.5.3.2 Open and Axial Coding

An inductive approach to data analysis was used, allowing meaning to be constructed by the interview participants (Creswell, 2009). The transcripts generated from the interviews were interpreted using 'open' and 'axial' coding, conducted in Dedoose (version 8.0.36), a web-based software application for qualitative and quantitative data management and analysis. Open coding was used to apply conceptual labels or codes to the data, based on the participants' own words (Robson, 2002). Axial coding was then used to categorize the open codes, and the data were further explored for relationships between the categories, including themes and patterns (Robson, 2002). After one round of open and axial coding, the resulting codebook was compared to the deductive conceptual framework based on the literature. It was determined that two levels of codes fit well

within the four themes that were conceptualized[6] based on the literature, and thus the themes could be used as the highest-level codes.

1.5.4 Application to research questions

In this study, both quantitative and qualitative methods are applied in a pragmatic approach to investigate pro-environmental behaviour change questions from the perspective of multiple stakeholders and different scales. The literature was used both deductively to test hypotheses and inductively to identify emerging patterns from the data collected. Given the "wicked" nature of anthropogenic climate change and the time-sensitive need to transform to a sustainable energy consumption culture, the pragmatic openness to applying a range of methods suitable to addressing facets of the problem is suitably justified.

1.6 Organization of Thesis

The four remaining chapters in this thesis include three discrete manuscripts addressing distinct research objectives, and a conclusion chapter that synthesizes and presents the overarching findings related to the broader aims of this doctoral pursuit. Chapters Two, Three and Four have each been written as manuscripts for submission to three different academic journals as joint-authored publications[7]. Since these manuscripts must be standalone documents, there is some repetition of theoretical grounding and empirical context between them. That said, the manuscripts build upon each other, and make use of different methodological approaches and instruments to chart the progression of understanding regarding pro-environmental behaviour change theories and their application to energy conservation intervention design and implementation (see Table 1 for overview).

[6] The literature on behaviour within organizations and commercial buildings was found to utilize terminology that was presented in the interviews. Given the pragmatic nature of the research topic, and the level of awareness of energy management and sustainability within the commercial real estate sector, there was a high degree of congruency between the deductive conceptual framework and inductive codes.

[7] Chapter 2 – Whitney, S., Lynes, J.K., Demaine, J., McLevey, J., & Graham, S.A
Chapter 3 – Whitney, S., Dreyer, B., Riemer, M., & Rowlands, I.H.
Chapter 4 – Whitney, S., Dreyer, B., & Riemer M.

Table 1: Overview of Dissertation

	Dissertation		
Overarching objectives	Investigate conservation and demand management (CDM)/voluntary behavioural modification Inform public policy in Ontario regarding the efficacy of current CDM planning and implementation Make recommendations for improving existing/designing future CDM programs in order to achieve greater conservation outcomes		
Chapter	**Two**	**Three**	**Four**
Type of study	Scoping review	Case study	Case study
Context	Pro-environmental behaviour change (PEB)	Ontario - Stakeholder perspective	Ontario and Alberta - Industry sector perspective
Objectives	Assess current state of literature Examine intervention design and implementation and implications for CDM public policy	Examine Conservation and Demand Management (CDM) performance of local distribution companies (LDCs) from 2011-2014 Explain variability in achievement and rate of change in achievement between LDCs	Examine energy management in commercial office buildings Focus on motivations and barriers of stakeholders in different contexts
Assumptions (feeding into Methods)	Human disturbance causes significant environmental degradation Interventions encourage pro-environmental behaviour (PEB) to reduce impacts	Scrutiny (oversight and practitioner) over spending on conservation programs Fiduciary responsibility to ensure efficiency and effectiveness of spending	Increased investment in energy retrofits and participation in behavioural programs required to reduce performance gap
Theoretical orientation	PEB critical to mitigating climate change	CDM provides environmental and social benefit; energy efficiency and conservation are cost effective relative to other methods of supplying electricity	Energy system and commercial buildings as a system System-level barriers to engagement (e.g., 'split-incentives') exist
Methods	Network Analyses (Qualitative Focus)	Quantitative Analysis Multi-level modelling (MLM) with two levels of analysis	Qualitative analysis Semi-structured interviews and open/axial coding
Identified gaps in Literature	Previous integrative review of the PEB literature conducted in 2008	Existing benchmarking focuses on economic and operational indicators of performance; limited empirical research on CDM performance	Paucity of literature on improving energy efficiency of commercial properties from systems perspective
Significant, original contribution to knowledge	Assessment of structure and research fronts and implications for public policy from interventions perspective	Steps towards understanding the correlation between conservation performance and other operations metrics	Comprehensive characterization of commercial buildings as systems in order to reduce performance gap
Global contributions	Empirical evidence to support several high-profile debates within Ontario (and nationally) related to energy conservation: general efficacy of conservation programmes as currently designed, the reason(s) why some LDCs are more 'successful' than others in achieving CDM targets, greater understanding of the impact of split-incentives in the commercial sector, and opportunities for achieving greater energy savings from this sector (identified as the 'key' in the Achievable Potential Study).		

Chapter Two addresses research Objective One using a scoping review. The chapter maps out a network visualization of the pro-environmental behaviour change literature, post-publication of the *Journal of Social Issues,* Vol. 56, Issue 3 (2000), using co-citation analyses and bibliometric coupling, along with several analytic techniques from the information science discipline. This JSI 2000 special issue brought together several prominent authors in the field, and includes two of the highest cited papers about environmentalism, to-date. The manuscript, titled *Visualizing pro-environmental behaviour change research: A bibliometric review of literature*, will be submitted to Environment & Behaviour. This journal was selected because it attracts broad readership within the field of environmental behaviour, and because it has previously published different types of review articles investigating the specific subsets of the environmental behaviour change literature (e.g., Karlin et al., 2014; Lokhorst et al., 2013).

Chapter Three addresses research Objective Two. It builds upon the findings of Chapter Two and seeks to expand understanding about the determinants of local distribution companies' achievement of energy (electricity) conservation targets, set at the provincial level, in Ontario. The manuscript, titled *Conservation and demand management – Determinants of electricity distribution utilities' achievement of CDM targets in the Ontario context*, will be submitted to Energy, Research & Social Science. This journal was selected because of its broad examination of the relationship between energy systems and society, and because it has previously published bibliometric review articles investigating energy-related literature (e.g., Gaede & Rowlands, 2018)

Chapter Four addresses research Objective Three. It also builds upon the findings of Chapter Two, and seeks to expand understanding about the motivations and barriers for building management and staff, as well as leadership with organizations that lease commercial office space, to engage in sustainable energy management initiatives. The manuscript, title *Closing the performance gap: Motivations and barriers to sustainability in commercial buildings*, will be submitted to *Nature Climate Change*. This journal was selected because of its broad scope in the field of climate change. It has previously published articles investigating the psychological constructs of environmental beliefs and behaviours (e.g., Jost, 2018).

Chapter Five recalls the purpose and objectives of the thesis and summarizes the major findings from the three manuscripts, presenting overarching themes. The individual findings are then synthesized into broader research contributions that represent significant, original, and relevant contributions to academic knowledge regarding the phenomena of interest. The empirical nature of the examination of LDC achievement with respect to Ontario's electricity conservation targets and the motivations and barriers of stakeholders within Ontario and Alberta's commercial buildings sector also produced several interesting findings for practitioners and policy makers in this space, which are also provided. Finally, the limitations of these studies are explored, along with recommendations for future research.

Chapter 2 - Pro-environmental behaviour: A scoping review

2.1 Introduction

It has been widely recognized and documented that human disturbance is causing significant environmental degradation, and this impact continues to increase (e.g. Maniates, 2001; Rosentrater et al., 2012; UNEP, 2009, cited in Webb, 2012). For example, the most recent Synthesis Report from the Intergovernmental Panel on Climate Change (IPCC) clearly illustrates that recent anthropogenic emissions of greenhouse gases are the highest in history, and the associated climate changes have widespread impacts on human and natural systems (IPCC, 2014). Reducing environmental degradation relies significantly on changing human behaviour (Zelezny & Schultz, 2000). Mandatory behaviour change can be achieved through policy instruments such as regulation or incentives (e.g., Jacobsen & Kotchen, 2011). However, many actions that negatively affect the environment are beyond the control of such instruments (for political and practical reasons) (e.g. Cialdini et al., 1998; Chapells & Shove, 2003; Kinzig et al., 2013). In such contexts the onus is left to individuals to exhibit voluntary 'environmentally-responsible behaviour' (ERB).

ERB can be broadly defined as actions (including the associated psychological constructs of intention, attitudes, beliefs, motives, and values) intended to lessen the impact of human behavior on the natural environment (Zelezny & Schultz, 2000). Similarly, Kollmuss & Agyeman (2002) use the term 'pro-environmental behaviour' (PEB) to refer to behavior that consciously seeks to minimize the negative impact of one's actions on the natural and built world. The emphasis on conscious choice is mirrored in Stern's (2000) definition of environmentally significant behaviour (ESB) as behaviour (i.e. from the actor's standpoint) that is undertaken with the intent to benefit the environment. While there are nuanced differences between these various terms, the similarity in their definitions and theoretical constructs permit the terms to be used interchangeably throughout the remainder of this paper.

ERB is a crucial component of mitigating climate change and ultimately achieving environmental sustainability (e.g. Hedlund-de Witt, 2012; Peattie & Peattie, 2009; Sioshansi, 2011). Howell (2013) quotes Her Majesty's Government: "Encouraging conservation in the huge range of individual and household-level behaviours that contribute to climate change is a significant part of the government's climate change mitigation strategy" (p. 281). In current Western capitalist democracies, individuals have been cast as both consumers and citizens, the latter being a critical role as drivers of change in the Neo-liberal governance of environmental [and other] issues by the state, as well as corporate actors (Barr, Gilg, & Shaw, 2011). Indeed, the growing literature on environmental education aims to make "present and future citizens capable of acting on a societal as well as a personal level" (Jensen & Schnack, 1997, p. 164), and plays a critical role in changing and addressing lifestyles and attitudes, and in altering individuals' and societal behaviour towards sustainability (Vicente-Molina et al. , 2013). Empirical evidence suggests that strong cultural conceptions of fairness and obligation exist, reflecting the propensity of people to exhibit both self-serving and other-serving behavior (Kinzig et al., 2013). Nevertheless, a growing body of research on environmental education and PEB shows that appealing to people to do the right thing or to protect the environment, rarely succeeds in increasing levels of PEB (Nolan et al., 2008). In addition, many studies have shown that, although the majority of consumers are generally 'pro-environmental', a large disparity between attitudes and behaviour

is still prominent (e.g. Kollmuss & Agyeman, 2002; Litvine & Wüstenhagen, 2011; Wilson & Dowlatabadi, 2007). This disparity is coined the 'value-action gap' (Blake, 1999), and the challenge for environmental practitioners has become how to motivate individuals to adopt ERB, and how to create a culture of environmentalism. Interventions – regulations, policies, programs, measures, activities, or events aimed at influencing pro-environmental behaviour – are needed because individuals will generally not partake in conservation behaviour of their own volition, due to market and non-market failures such as misaligned incentives and institutional barriers (e.g. Welsch & Kühling, 2010; Wilson & Dowlatabadi, 2007).

Environmental psychologist Robert Gifford (2014) argues understanding human behaviour can solve many environmental problems, because it is the root of the problems (recognizing, of course, that there are influences at other levels of analysis that are beyond individual control). Gifford notes three challenges: 1) Learning how individual influences of behaviour such as (but not limited to) values, attitudes, norms, habits, demographic factors, etc., moderate and mediate one another, 2) Learning which domains of ERB (the 'big 5' being energy conservation, transportation, food, waste disposal, and material purchases) are most influential in which social domain (private, public, or organizational, or activist – Stern, 2000), and 3) Deepening understanding of how society's production and consumption of goods and services and broader social and political influences impact the formation of individual values, attitudes, and behaviour. Other researchers are answering this call for action by investigating ERB in specific contexts such as the workplace (Ciocirlan, 2017; Norton, Zacher, Parker, & Ashkanasy, 2017), the home (Sunikka-Blank & Galvin, 2016; Wilson et al., 2015), and when vacationing (Rishi, Jauhari, & Joshi, 2015). Given the pressing need to transition to more sustainable, low-carbon societies (Dumitru et al., 2016), researchers and practitioners alike need a comprehensive understanding of the factors that cause environmental behaviours and PEB, and apply this knowledge to interventions in order to achieve the necessary behaviour change (Steg & Vlek, 2009). Steg & Vlek's (2009) review appears to be the most recent integrative assessment of the contribution of environmental psychology to this understanding; as almost a decade has past, a current appraisal of the field as a whole is needed, as well as an evaluation of the extent to which current knowledge on ERB is being applied to the design and implementation of interventions. This paper aims to address these needs, first with a literature review of the development of environmental behaviour change theories, followed by an analysis of the structure of the field, and commentary on the influence of this literature on interventions for promoting ERB.

The structure of this paper is as follows. After this introductory section, the literature on pro-environmental behaviour is discussed in Section 2. Sections 3 and 4 present the methodology for and the results of the data analysis. A concluding Section 5 follows the analysis of results, including a reflection of the implications of the findings for understanding the integration and implementation of theory in interventions to promote ERB.

2.2 Historical development of ERB - A brief literature review

2.2.1 The birth of environmentalism

Arguably, environmentalism in North America was born in the 1960-70's. Powerful books such as Rachel Carson's *Silent Spring* and Meadows et al.'s *Limits to Growth* catalyzed a movement of social activists,

aware of the negative impacts of human intervention on nature, and dedicated to holding industry accountable for the harm caused to the environment. In the 1960's and 1970's environmentalism grew from its original focus on pollution to include resource depletion and the consequential limits of economic growth. Recognition of human behaviour as the cause of environmental degradation (and a threat to humans and other species) spurred the application of behavioural analysis as a means of environmental protection (e.g., impact of anthropogenic behaviour on air and water quality). *Environment & Behavior* published two notable journal issues focused entirely on behavioural aspects of resource management and environmental quality and environmental education (June and September 1971, respectively). For example, researchers began to study ERBs, such as carpooling and recycling, as well as destructive behaviours, such as littering and wasteful consumption; it was demonstrated that interventions could achieve behavioural modification, and effectively increase ERBs and decrease destructive behaviours (Lehman & Geller, 2004).

The evolution of environmental behaviour change research was further catalyzed by the World Commission of Environment and Development's (WCED's) book *Our Common Future* (1987), which popularized the definition of sustainable development. A period of heightened awareness and debate concerning anthropogenic climate change (and the appropriate human response) began in the late 1990's. The increased spotlight was placed on the environmental impacts of human activity due to catastrophic crisis events (e.g., Exxon Valdez oil spill, 1989) and the prediction of significant socio-economic impacts of climate change from international agencies (e.g., Intergovernmental Panel on Climate Change, IPCC, 2nd Assessment Report, 1995). Western capitalist democracies have increasingly underscored the role of consumers in promoting and achieving environmental sustainability, through social change, in the fusion of consumer and citizen identities (Barr et al., 2011). Without entering the debate about whether this framing is appropriate, the prevalence of ERB depicted as a self-identified characteristic which can advance environmental sustainability (if widely adopted throughout society) in the literature has been recognized. Increasingly, researchers also offer arguments that the individualization of responsibility ignores broader issues of institutional power (e.g. Maniates, 2001) and social practices (e.g. Shove, 2010), which question the ability of the 'citizen-consumer' in bringing about the appropriate response required to mitigate climate change.

2.2.2 A historiography of major behaviour change theories

A review of literature, synthesized below, reveals four major advancements in the understanding of behaviour change and decision-making theory. First, the complexity of the human decision-making process has been recognized; such that individuals are no longer modeled as purely rational actors (Kahneman, 2003). Second, the concept of self-identity has evolved to include numerous 'non-self' values that can be measured and/or predicted (Hedlund-de Witt, 2012; Hinds & Sparks, 2008). Third, there has been a shift from treating individuals as socially isolated decision-makers to emphasize status as members of various societal and cultural groups, all which have normative influence on individual values, attitudes, and behaviour (Cialdini, Robert B; Demaine, L.J.; Sagarin, B.J.; Barrett, D.W.; Rhoads, K.; Winter, 2006; Getz, Donald; Page, 2015). Norms have been shown to mediate between the identity of the individual and that of the group(s) to which the individual belongs. Finally, a new class of models emphasized the influence of external factors from higher levels of scale (e.g., societal constructs) on individual decision-making,

resulting in the inclusion of feedback loops between the determinants at different scales and individual behaviour change (e.g., Foster-Fishman, Nowell, & Yang, 2007; Groesser, 2014).

2.2.2.1 The growth of behaviour change models

Rational choice models are social-psychological process models that portray a clear, sequential, and causal relationship between the possession of information (e.g., environmental awareness), the impact of knowledge on attitude, and behaviour (e.g, PEB) (see Figure 4 for a depiction of an information-based, rational model of behaviour) (Darnton, 2008). Individuals are assumed to be "utility maximizing", such that the "best" option will always be selected, based on economic or another subjective benefit. In other words, decisions should be predictable. The recognition of limits to individuals' capacity for deliberation in many contextual situations, and inclusion of cognition into rational choice models is a major contribution of psychology to the field of economic analysis. Simon's (1955) model of "bounded rationality" of humans, where cognitive heuristics are applied until an acceptability threshold is met, has become a de facto model in the behaviour change literature, serving as a guideline in many environmental policy tools aiming to influence individuals, such as the Precautionary Principle (e.g. Grant & Quiggin, 2013). Similarly, Kahneman & Tversky's (1974) "judgement heuristics" explained decisions made under uncertainty (e.g. time pressure, heavy cognition load) by positing that access to 'rule of thumb' information reduces probability calculations into simpler judgements, reducing the amount of data processed for every decision.

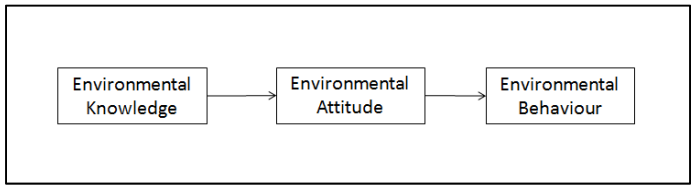

Figure 4: An information-based model of PEB (reproduced from Kollmuss & Agyeman, 2002)

Although information (as a source of knowledge) is a pre-requisite for many behaviours, there is often a "gap between the possession of environmental knowledge and awareness, and displaying pro-environmental behavior" not accounted for in earlier rational choice models (Kollmuss & Agyeman, 2002, p.240). Evolved linear models offer a 'bridge' to explain "the difference between what people say and what they do" (Darnton, 2008, p. 10), addressing the disparity between attitudes and behaviour, coined the "value-action gap" (e.g., Blake, 1999). For example, Fishbein and Ajzen's Theory of Reasoned Action (TRA) (1975), bridges the gap between attitude and behaviour with the construct of 'intentions', holding that *intentions lead directly to behaviour*. The development of theories to explain behavioural intentions was the next major advancement in field of behaviour change.

2.2.2.2 Explaining intentions to behave

Klöckner's (2013) structural equation modelling of the determinants of environmental behaviour, based on meta-analytic data, showed that intentions completely mediate behaviour when included in behaviour change models. In turn, both personal and social norms are assumed to directly influence behavioural intention (Klöckner, 2013). Personal and social norms are described as guidance for individual and societal behaviour, the distinction coming from the influence of internal or external sanctions (Darnton, 2008). Personal norms have also been described as a person's feeling of moral obligation to act, and used to explain

altruistic or 'helping' behaviours, such as in Schwartz's (1977) Norm Activation Theory. Similarly, Stern et al.'s (1999) Value Beliefs Norm (VBN) Theory of PEB links value, categorized as biospheric, altruistic, and egostic, to behaviours such as environmental activism or non-activist behaviour in the private or public sphere, or in organizations. Dunlap et al.'s (2000) New Ecological Paradigm (NEP) Scale is an example of a widely used tool to measure such pro-environmental orientation, and is often used as a predictor of PEB. The premise of such proxies is that the degree to which environmental values are aligned with an individual's concept of self, or self-identity, is correlated with PEB.

In the early 2000's, it was emphasized that for PEB to be sustained, behaviour change had to result from intrinsic motivation (i.e. from self-determined or endorsed behaviour) as opposed to extrinsic motivation. In their Self-Determination Theory (SDT), which states that within social contexts, people have a natural tendency to try to satisfy basic innate psychological needs for competence, relatedness, and autonomy, Ryan & Deci (2000) mapped out a continuum showing types of motivation, along with regulatory styles, loci of causality, and corresponding self-regulation processes. It is notable that SDT includes three sub-categories of extrinsic motivation that range from 'somewhat external' to 'internal' with respect to the locus of causality; essentially, the extent to which an individual interprets and views regulation as important has a significant impact on their motivation to comply with the regulation.

According to SDT, 'pure' intrinsic motivation, where behaviour comes from self-interest, enjoyment, and inherent satisfaction, is the ideal type for satisfying the needs for competence, relatedness, and autonomy that allow individuals to experience well-being, and place more emphasis on intrinsic aspirations, such as affiliation, personal growth, and community, versus other goals that do not directly contribute to (and may even detract from) the basic needs, such as extrinsic aspirations of wealth, fame, and image (Ryan & Deci, 2000). SDT is well supported as a framework explaining predictors of PEB within the general public; there is a wealth of literature showing that PEB (both frequency and variety) correlates most highly with self-determined motivation (Green-Demers, Pelletier, Seguin, and others, cited in Darner, 2009).

Extrinsic motivations fail to sustain PEB in the long-term, because once incentives or punishments (for performing or failing to perform) are removed, behaviour will only continue if individuals are self-determined (Pelletier 1999; 2000, cited in Darner, 2009). Similar to self-determined motivation, Schultz (2000) argued that the types of environmental concern expressed by individuals are fundamentally linked to the degree to which nature and other people are included one's cognitive relation to self, and whether people define themselves as independent of, or interdependent with other people and/or with all living things (i.e. nature). Based on this three-factor model of environmental concern, all types of attitudes can lead to PEB; however, biospheric (interdependence with nature) leads to the broadest base of environmental action (Schultz, 2000). Both SDT, as applied to PEB, and the three-factor structure of environmental concern are consistent with Stern's (2000) model of value-based-norm theory of PEB and other behaviour change theories that fill the 'value action gap', or void between environmental attitude and behaviour with various constructs such as intention and barriers (e.g. Kollmuss & Agyeman, 2002; Mckenzie-Mohr, 2000).

2.2.2.3 Emphasis on normative social influence

In addition to environmental value as a part of self-identity, the role of normative social influence on PEB has been increasingly recognized over time. Bicchieri (2006) defines a social norm as a behavioural rule for a situation (or type of situations) that lives up to two criteria: a sufficiently large share of the population (1) knows the rule and knows that it applies to this particular type of situations and (2) conditionally prefers to conform to the rule in this type of situation. According to Thøgersen (2008), the first criterion is uncontroversial, included in all prevailing definitions of social norms. This is clear, since by default, unless a rule is known, it cannot be intentionally followed. The second criterion is new, in that it implies that "most people acknowledge the need for cooperation in social dilemmas and that they therefore prefer to cooperate, under certain conditions" (Thøgersen, 2008, p. 459).

There are two types of social norms, injunctive (extent to which behaviour is approved or disapproved of within society, or beliefs about others' compliance) and descriptive (extent to which the approval or disapproval is common within society, or beliefs about others' expectations for compliance) (e.g. Steg & Vlek, 2009). A major finding from research conducted in this area is the confirmation that injunctive and descriptive norms influence cooperative behaviour synergistically, rather than additively, making it difficult to separate their effects on behaviour, or answer why people behave the way they do (Thøgersen, 2008).

Some progress has been made in distinguishing the effects of injunctive and descriptive norms in certain types of situations. For example, in a study on high levels of a socially disapproved behaviour, removal of petrified wood from a protected National Park, it was found that injunctive norms with strong, negatively framed words were the most effective in reducing the instances of behaviour, while descriptive norms with strong framing were the least effective (Cialdini et al., 2006). Descriptive norms were also found to produce an undesirable boomerang effect in a study of household energy conservation, if households were already using lower than the stated average consumption, although it did reduce usage in households that were using more than the average consumption (Schultz, Nolan, Cialdini, Goldstein, & Griskevicius, 2007).

In the health field, it was found that descriptive norms using positively framed messaging ("We are becoming healthy heroes. You can too.") were successful in engaging community residents in a healthy eating and exercise initiative (Stead, Arnott, & Dempsey, 2013)[8]. Recent research has also addressed the possibility of individuals facing conflicting norm behaviour from their multiple in-groups, and suggested that this conflict can have a motivating effect on PEB, such that the more divergence in beliefs about the norms of individuals' in-groups, the more motivated they are to act to reduce their [own] environmental impact (R. I. McDonald, Fielding, & Louis, 2012); norm conflict was associated with reduced water usage, and perceived effectiveness partially mediated additional PEB intentions, as individuals sought to spread the positive norm behaviour to non-acting groups.

Interestingly, descriptive norms are used most often in Public Service Announcements (PSAs), and other types of persuasive interventions used to target a variety of social issues (Cialdini et al., 2006). The research on effectiveness of social norms indicates that campaigns using normative appeals must be properly crafted

[8] It is recognized that this messaging was part of a much broader campaign, developed through participatory research within the community, and that testing the effectiveness of injunctive vs. descriptive norms was not part of the scope of the study.

and considered in the distribution of the targeted behaviour within the population and the approval of the behaviour, in order to avoid unintended consequences. Also noted that the effect of norms is under-detected (Nolan et al., 2008), and individuals also change their behaviour once they know they are being observed (e.g., Brick, Sherman, & Kim, 2017).

Studies have shown great success when relevant stakeholders are actively engaged throughout the design and implementation of interventions. For example, McKenzie-Mohr's 5-step Community Based Social Marketing (CBSM) framework has been used in hundreds of campaigns promoting various PEBs (Kassirer, Korteland, & Pedersen, 2014; Mckenzie-Mohr, 2000; McKenzie-Mohr & Schultz, 2014; Senbel et al., 2014). Public commitments can be used to enhance participation in sustainable behaviours where low motivation exists, as the visibility of an action increases the likelihood that individuals will want to comply with social norms surrounding the behaviour (e.g. curbside recycling) (Mckenzie-Mohr, 2000; Thomas & Sharp, 2013). Research has also shown that the effect of making personal commitments can last months after an intervention has ended, effectively creating new habitual behaviours, providing that social norms have been successfully activated (Matthies et al., 2006, cited in Klöckner, 2013). This result points to the need for frequent and continuous prompts to remind individuals that in a given situation, the norms apply (Klöckner, 2013). Prompts have been found to be an effective strategy when a target behaviour is clearly defined, relatively easy to perform, and when the prompt (or message) can be placed in closed proximity to where the target behaviour is performed (Lehman & Geller, 2004). These findings demonstrate the importance of 1) clearly understanding the motivations of the targeted audience for a given intervention (including the perceived benefits and barriers to the desired behaviour change), and 2) having actionable frameworks, incorporating the most advanced behaviour change research in the field.

2.2.2.4 Incorporating external factors and feedback loops into behavioural models

Building upon the theme of normative influence, psychological models of behaviour change have evolved to include the concept of social or group identity and culture, along with other external factors and the iterative process of influence between the scales of analysis. Aside from social norms, other normative influences of individual attitude and behaviour include social and cultural traditions, and family customs; "if the dominant culture propagates a lifestyle that is unsustainable, pro-environmental behavior is less likely to occur and the gap between attitude and action will widen" (Rajecki, 1982, cited in Kollmuss & Agyeman, 2002, p. 242). Indeed, ecological economists have argued that social learning can be visualized as a positive feedback process (see Figure 5) or "circular causality" between individual habitual actions, institutional habitual thoughts, and societal culture, more broadly (Maréchal, 2009, p.78). This leads to self-perpetuating socio-technical systems (STS) and "path dependence" or "lock-in" of incumbent societal structures such as fossil fuel energy and infrastructure (David, 1985; Arthur, 1988; Brette, 2003; and others, cited in Maréchal, 2009). Strong social and cultural perceptions also exist about life cycle stages, transitions between stages, and what it means to be in a certain stage of life (Kollmuss & Agyeman, 2002). For example, many expectant mothers feel anxious about the arrival of a baby, and may attach symbolic significance to commodity items such as strollers, taking them to signify fitness as a parent (Thomsen & Sorensen, 2006); there is significant market potential to exploit this common angst (or common anxiety, for that matter) to the

benefit or detriment of consumers, by either reducing or increasing it, as socialization and acceptance is an important consideration for individuals.

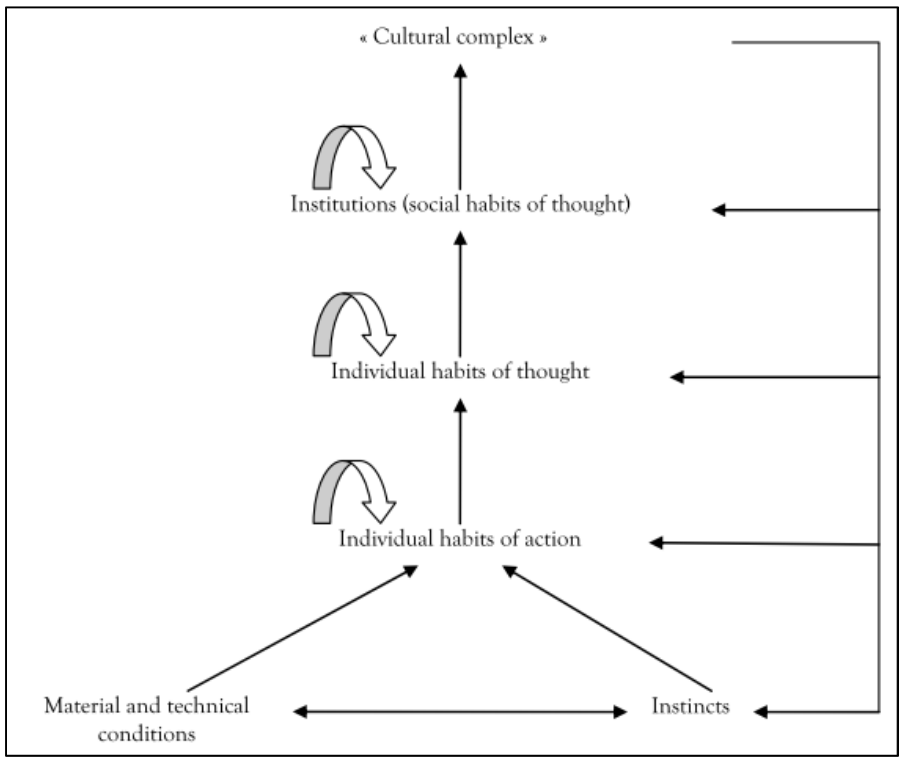

Figure 5: Veblenian Process of Institutional Self-Reinforcement (reproduced from Marechal, 2009)

This cultural influence is also recognized in Vlek et al.'s Needs Opportunities Abilities (NOA) model of consumer behaviour (1997), as culture is one of the five macro-level factors that impact behaviour, along with technology, economy, demography, and institutions. Similarly, day-to-day practices that are resource-reliant (e.g., showering) are embedded within the social-technical configuration of material culture (Shove, 2010), including infrastructure (Webb, 2012).

Recently, the relationship between repetitive behaviours and the desire to reduce mental burden through automaticity of activities has been explored in more detail. There is general consensus that habits develop through incremental strengthening of the association between a trigger (situation, or cue) and an action. While historical research has largely focused on habits that are well-established, researchers have begun to investigate the process of habit formation, and how this process can be influenced in order to promote desired behaviours (e.g. Lally, Van Jaarsveld, Potts, & Wardle, 2010). Habitual behaviours that are entrenched in social and cultural structures are more resistant to change than behaviours that are less entrenched (e.g. Redman, 2013) and will therefore require greater intervention in order to form new habits.

2.2.2.5 The state of knowledge

Based on the history of behaviour change research focused on ERB, as described above, three lessons emerge: 1) the theories/approaches originate from distinct disciplinary perspectives, 2) the major conceptual and methodological contributions build on the ones prior, likely in attempts to address criticisms and/or

limitations, 3) there appears to have been a temporal shift in theoretical and empirical research on ERB from social-psychological process models towards feedback models, with multiple and often complex loops between different levels of analysis. The synthesis of research in this literature review was conducted as the first step in advancing knowledge on ERB, specifically the application of environmental behaviour change theories to the design and implementation of interventions.

2.2.3 Current research

The brief historiography presented above is not intended to be an exhaustive review of the existing literature. Rather, it was provided to highlight the growth and maturation of behaviour change theory over time, and the implications of the progress achieved for empirical research in the field of ERB, including the design and implementation of interventions. Scholars have traditionally used literature reviews and meta-analyses to make sense of historic work within a field (Schmidt, 2008). One limitation of narrative literature reviews is the subjective bias of the researcher, and the lack of rigor in the methodology (Tranfield, Denyer, & Smart, 2003). Systematic reviews – a formal and structured approach to conducting a literature review – is argued to be one of the most effective ways to position the academic landscape of a field of study (Wilkie & Moore, 2003), but are time-consuming to conduct due to the need for collection and analysis of substantial amounts of data in order to comprehensively benchmark the progress of a discipline and suggest future directions (Williams & Plouffe, 2007). If a systematic review reveals sufficient and appropriate quantitative data to perform statistical analysis, a meta-analysis (extraction of effect sizes for one or more outcomes, followed by a statistical model to analysis the heterogeneity in outcomes) can be performed for the resulting studies (Gurevitch, Koricheva, Nakagawa, & Stewart, 2018). Science mapping (using bibliometric methods to produce spatial representation of how disciplines, fields, specialities, papers, authors, and journals relate to one another) in increasingly being used in the synthesis of research (Zupic & Cater, 2015).

Narrative literature reviews are subjected to bias by the researcher and often lack rigor (Tranfield, Denyer, & Smart, 2003). Bibliometric methods employ a quantitative approach for the description, evaluation, and monitoring of published research. These methods have the potential to introduce a systematic, transparent, and reproducible review process and thus improve the quality of reviews.

Reviewing past research not only provides an overview of the progress achieved in a particular field of study but also identifies gaps and extends prior studies (Creswell, 2009). Furthermore, assessing previous research efforts reveals the theoretical awareness, methodological sophistication, and the direction of research in a field of study (Hesse-Biber, 2010; Krippendorff, 2004; Williams & Plouffe, 2007). Considering the implications for intervention design and implementation and conservation and demand management (CDM) public policy, a review of past research serves to establish the foundation of knowledge (e.g., assumptions about pro-environmental behaviour) on which are based policy decisions are based.

This paper seeks to address the following research questions:

1. What are the important/influential communities of scholarship (as evidenced by highly cited peer-reviewed publications) that have shaped the current structure of ERB research?

2. To what extent is the current literature on ERB engaged with specific themes, as identified by important/influential publications?

To answer these questions, three quantitative methods from the information science and bibliometrics literature are utilized. First, the relative importance/influence of the articles published in the field is evaluated using a method called Multi Reference Publication Year Spectroscopy (Multi-RPYS), which is used for identifying years and publications that have been especially important in the historical development of a field. A co-citation network analysis is then developed to assess the structure of the field, and whether distinct research clusters exist, and whether existing clusters map onto themes. Second, a bibliometric coupling network analysis is developed to determine the current level engagement with the issues identified in important/influence publications (identified in Step 1).

2.3 Methodology

2.3.1 Reference Publication Year Spectroscopy (RPYS)

To determine the relative importance/influence of highly cited publications, it is necessary to first build a dataset containing a comprehensive representation of the environmental behaviour change field, more broadly.

Given the clearly defined scope of the study, the inclusion criteria were as follows:

1. A dataset containing a comprehensive representation of the environmental behaviour change field, more broadly. A search was conducted using the Web of Science (WoS) for all articles using the terms: 'environmentalism', 'pro-environmental behaviour'[9], or 'environmentally significant behaviour' in the topic. Articles using the terms 'behaviour change' and ('environmental' or 'sustainability') within five (5) words of each other, also within WoS' topic field, were also included. Several categories that contained irrelevant articles (e.g., Polymer Science, Agricultural Health, etc.) were then excluded (Appendix A in Chapter 2 contains the Boolean search formula, including exclusions).
2. Research published in English[10], due to practical constraints
3. Peer-reviewed articles published in academic journals as opposed to books, book chapters, conference presentations, or other reports, with exclusive use of the Web of Science (WoS) database via the University of Waterloo's library system
4. Articles addressing the use of pro-environmental behavior theory on design and implementation of interventions, as defined by Wilson & Dowlatabadi as any "regulation, policy, program, measure, activity, or event that aims to influence behavior" (2007, p170), or the implications of PEB theory on interventions.
5. The metadata for all 4,767 articles that were identified in this search was then downloaded (see Appendix A for full Boolean search formula, including exclusions).

[9] Both the American and British spelling of behaviour (behavior) were used in the search.
[10] The language bias introduced by this inclusion criterion was acknowledged and deemed acceptable, as many researchers in the field publish in English.

While it is possible that some materials were missed due to these restrictions, there is justification based on trends in literature on pro-environmental behaviour where many authors choose to present their most salient findings in article format (e.g., Gunningham 2009; Holley, et al. 2012). The criteria also defined a set time period between 2000 and December 2017 when the final article search was conducted. Limiting the dataset to a reasonable quantity of articles for analysis by a single researcher was required in order to complete the manuscript within the restrictions imposed by the doctoral process.

RPYS is a new quantitative method – proposed in articles by Marx, Bornmann, Barth, and Leydesdorff (2014) and Marx and Bornmann (2014) – for identifying specific years and publications that have played important roles in the development of research literatures. It is the most recent development in the field of historical bibliometrics, which has been an important specialty within bibliometrics since the 1960s. RPYS begins by mining the citations from the references lists from a body of literature (in our case 4,767 articles on environmentalism and pro-environmental behaviours) and groups citations based on the years in which they were published. It then produces a frequency distribution, sorted from earliest publication years to the most recent. To control for the increase in number of publications every year, the data is standardized by computing the extent to which each year deviates from a 5-year median. These scores – typically in the form of percentages – are then plotted as line graphs. Prominent peaks in the graphs reveal years in which important articles and books were published (given the standardization described, above, these peaks represent influence above and beyond the median growth in the field). One can then assess the items that were published in any given year and determine which articles and books were the most heavily cited, and are therefore important/influential to the research area in question.

Multi-RPYS is an extension of this general method. In short, *n* series of RPYS analyses are conducted, for example every year. This reveals not only which years, books, and articles are important to a field, but *when* they are / were important. For example, a particular theory may have played a central role in research for, say, 10 years, after which it fell out of favor and was replaced by a competing theory. A standard RPYS analysis would detect the influence of the first theory, but it would not be able to identify the time frame when the theory was important, and when it fell out of favor.

In the results section, the results of both an RPYS and a Multi-RPYS analysis are reported. Generally, this method has been used to good effect in information science research to quantify the impact of historical publications on research fields (McLevey & McIlroy-Young, 2017).

2.3.2 Co-Citation Network Analysis

Co-citation analysis measures the frequency with which two (or more) articles are cited together in other documents, therefore identifying "cognitively related knowledge clusters" that have been accepted (via citations) by a network of researchers or followers (Fursov & Kadyrova, 2017). The method was developed in 1973 to study the linkages between the documents, in particular, their "semantical relatedness (Fursov & Kadyrova, 2017, p.1951). Gaede & Rowlands (2018) provide an in-depth rationalization for the use of co-citation analysis in the study of research fields, citing benefits such as the identification of specialties within a knowledge domain, measurement of author influence, and determining the network structure that connects the specialties and authors. There is a growing amount of literature making use of co-citation data to "map

the structure of science or identify different clusters of scientific research" (Wallace, Gingras, & Duhon, 2009, p.240).

To determine the extent to which the current literature on ERB is engaged with specific themes (i.e., in research clusters), as identified by important/influential articles, a co-citation analysis was conducted on a subset of the 4,767 articles compiled in Section 3.1 As described in Section 4.1, the *Journal of Social Issues* (JSI), Vol 56, Issue 3, published in 2000, was identified by the RPYS and Multi-RPYS as being an important/influential publication (comprised of 11 articles) in the ERB literature. Therefore, the co-citation analysis was restricted to a dataset of 3,224 articles that cite one of the articles from the special issue. In a systematic review, the quality of these articles would have been assessed using the Mixed Methods Appraisal Tool (MMAT) criteria (Pace et al., 2012) or an eligibility criteria (e.g., Staddon et al., 2016). Given that the goal is to better understand the importance/influence of the articles in the special issue, the quality of the articles in the dataset was not assessed, rather all articles were treated as equal. In building this dataset, the WoS database was used, exclusively, and may not have captured all of the literature that has cited the special issue. As an example, WoS returned 1,681 citations of Stern's paper, while Scopus listed 1,941 citations. However, it was deemed that WoS' indexing practices, including high standards for journal inclusion and careful vetting of predatory journals, would result in a sufficient representation of the field, balancing between imposing structure within the dataset and including unrelated work. Accordingly, minor differences between datasets have little effect on bibliometric analyses, which rely on social network analysis and keyword analysis to extract the underlying concepts that characterize a field of study. Thus, the findings can be generalized to provide a conceptualization of the research topics in this field.

Once the dataset of articles was restricted to citing publications from the original special issue, the co-citation network was extracted and analyzed, as detailed in the following subsection.

2.3.2.1 metaknowledge and link sparsification

First, the Python package metaknowledge (McLevey & McIlroy-Young, 2017) was used to extract a co-citation network from the 3,224 articles. In this network, each node is an item (i.e., a referenced publication) appearing in at least one reference list of the 3,224 articles. Edges are assigned between two items when they are co-cited, i.e. when they appear in the same bibliography. Each time a pair of items is co-cited, the edge weight between them increases by 1. The initial network, without any cleaning, consisted of 109,552 nodes (books or articles) and 7,419,710 edges (co-citations). Most of these co-citations only occur once (coined 'isolates' in the information science literature), and it is accepted practice to treat these occurrences as noise. To focus the analysis only on more meaningful co-citation patterns, any co-citations that did not occur a minimum of 3 times were removed, and then any nodes that did not have an edge weight of at least 3 (i.e. that are not co-cited with *any* items more than 3 times) were also removed. This resulted in a final network with 11,354 nodes and 115,605 edges.

In order to make sense of this very large network, a link sparsification method that identifies relationships embedded in cohesive groups was used (Lee, Nick, Brandes, & Cunningham, 2013; Nocaj, Ortmann, & Brandes, 2015). Rather than simply deleting edges that fall below some arbitrary threshold, this method uses an algorithm that identifies structurally embedded edges (a density function where an edge is weighted,

ranked, and reweighted in comparison to adjacent edges) and partitions clusters such that a 'backbone' of dense edges with inherent characteristics of strong social ties remains (Lee et al., 2013; Nocaj et al., 2015) It has been shown to be capable of revealing community structure in large 'hairball' networks, and has the advantage of being grounded in social scientific theories of networks and tie formation *as well as* graph theory. Using this method enabled the retention of more information about the structure of the network while still reducing the complexity involved in analyzing a network with more than 11,000 nodes and 115,000 edges. The final network, including only the 'core' articles included 609 nodes and 4,411 edges.

Finally, cohesive subgroups were identified – representing research areas, substantive problems, etc. – in the co-citation network analysis using the Louvain[11] community detection algorithm, a two-phased iterative partitioning method (Blondel et al., 2008). This particular approach was selected because it has been shown to do a better job of detecting valid communities in co-citation networks than other algorithms (Wallace et al., 2009).

2.3.3 Bibliometric Coupling Network Analysis

Bibliometric coupling uses the frequency with which two documents share references or citations as measure of their relatedness or connection, therefore identifying emerging fields and subfields within a broader knowledge domain (Zupic & Čater, 2015). The method was developed in 1963, a decade prior to co-citation analysis, to study the similarity between documents. Biscaro & Giupponi 2014) describe bibliographic coupling networks as lenses to view how knowledge is used and combined scientifically by authors within a field, therefore allowing inferences about the size of research communities and connections between topics that have yet to be linked.

Extraction and analysis of the bibliometric coupling analysis was performed using Sci2. Starting with the same 3,224 articles, the initial de-duplicated network consisted of 112,769 nodes (books and articles), and 205,021 edges (co-citations). After extracting the bibliographic-coupling similarity network and deleting the isolates, the network consisted of 3,256 nodes and 2,487,001 edges. Between each step in the analysis, the network was pruned using the MST pathfinder pruning algorithm, and isolate nodes were deleted. Once again, the Louvain Community Detection was selected as the resolution parameter, but rather than using link sparsification as in the co-citation analysis, an edge threshold weight of 10 was selected, which yielded a reasonable number of clusters, which when further analyzed, reflected distinct subfields. The network consisted of 1,143 nodes (isolates deleted) and 6,285 edges.

It is acknowledged that setting a relatively high minimum threshold for shared references produced a network structure of strongly connected communities. Generally speaking, the rationale for establishing a threshold in the analysis of a bibliometric coupling network is twofold. The first is based on the quantitative assessment of the similarity of two articles based on the number of references they share – the greater the number of shared references, the stronger the connection between articles (Zupic & Čater, 2015). That two articles within the same research area should have a single reference in common (giving them a

[11] The Louvain community detection algorithm is one (of many) methods to represent modularity (a measure of the density of connections between nodes) in the network (more dense connections between nodes in a community, less dense between nodes in different communities).

bibliographic coupling strength of 1) is not uncommon. Indeed, a minimum definition of a given research area is that articles within it are connected by at least one reference. For identified research clusters to be meaningfully partitioned, a stronger connection between articles must be observed. Thus, a threshold of shared references that is greater than 1 is necessary for an analysis of the research area. At the same time, an element of judgment is required. As the purpose of a social network analysis is to uncover patterns in a large set of citations, a representation of all connections in the dataset is no more helpful than examining the raw data itself. A large number of spurious connections within a network renders the underlying patterns unclear, making it necessary to remove the co-occurrences that have little meaning in order to extract knowledge from the network. The emergence of these patterns and meaning is dependent upon the interpretation of the researcher, who must determine "a cut-off threshold above which agents are to be regarded as being sufficiently similar to be, in effect, 'substitutable' for one another" (Scott, 2013, p.123). Thus, subjectivity is a necessary part of social network analysis. This is seen in setting the parameters that define how social networks are created and in the visualization of citation patterns:

> *"We selected the 1242 publications with at least eight citations for further analysis. For these publications, we determined the number of co-citation links and the number of bibliographic coupling links. These two types of links were added together and served as input for both our mapping technique and our clustering technique. In the case of our clustering technique, we tried out a number of different values for the resolution parameter Y. After some experimenting, we decided to set this parameter equal to 2. This turned out to yield a clustering with a satisfactory level of detail."* (Waltman, van Eck, & Noyons, 2010, p.633)

The common practice for co-citation analysis (a mapping technique) and bibliometric coupling (a clustering technique) to be used in a combined fashion for the analysis of bibliometric networks (e.g., Leydesdorff, 2004; Waltman, van Eck, & Noyons, 2010; Zupic & Čater, 2015) is noteworthy. Indeed, mapping and clustering techniques are viewed as complementary in the field of information science, because mapping provides a detailed visualization of the network structure (with restrictions on the more granular relationships) while clustering can be used to focus on more subtle connections (while providing only a course picture of the overall structure) (Waltman et al., 2010). For the current study, both co-citation analysis and bibliometric coupling are needed to answer the research questions, which investigate both the structure of the pro-environmental behaviour change field, and the most subtle connections or emerging research fronts.

2.4 Results and Analysis

2.4.1 RPYS Analysis

As previously discussed, the RPYS analysis identifies years that have been particularly important in the development of a literature. Once those years have been identified, one can then assess the key publications for those years.

The main result of the standard RPYS analysis is presented in Figure 6. The zero on the y-axis represents the baseline number of citations for the year, based on the 5-year moving median, as described in Section 3.1 Spikes below the baseline represent years in which the number of cited articles fell below the median, and spikes above the baseline indicate years of highly cited articles (based on publication year).

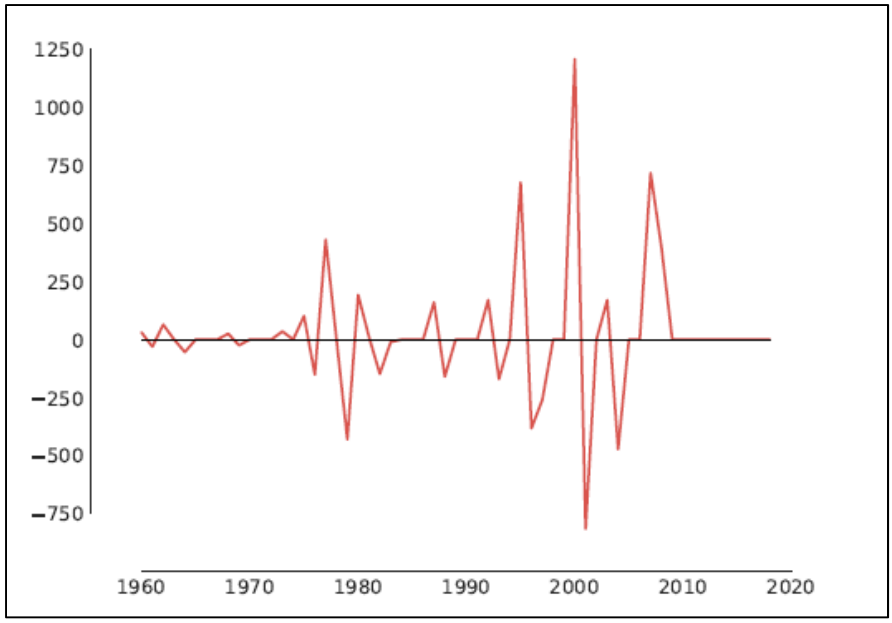

Figure 6: Standard RPYS for the 'environmentalism' literature

Prominent peaks in this graph (e.g., 1977, 1995, 2000, and 2009) represent key years in the development of the ERB literature. In 1977, the most cited publication was Schwartz's article "Normative influences on altruism," followed by Bandura's "Self-efficacy: Toward a Unifying Theory of Behavioral Change" and Ajzen and Fisbein's "Attitude-behavior relations: A theoretical analysis and review of empirical research". Although none of these articles explicitly discussed ERB, they nevertheless provided the foundation for environmental behaviour change theories, each contributing to the understanding of the attitude-behaviour relationship. Schwartz (1977) presented altruism or 'helping' behaviours as being caused by personal norms, specifically the activations of one's moral obligation to act. Bandura (1977) theorized that behaviour is predicted by the level and strength of self-efficacy, which develops through enactive, vicarious, and emotive-based processes. Ajzen and Fishbein (1977) demonstrated empirically that behaviour is consistent with attitude when it is directed at the same target and when it involves the same action, and inconsistent in different contexts and times. These works underpin current investigations of ERB including (but not limited to) models of decision-making in residential energy use (Wilson & Dowlatabadi, 2007), the impact of habitual behaviour on the 'value-action gap' (Howell, 2013), and the use of message framing to promote ERB (Abrahamse, Steg, Vlek, & Rothengatter, 2005; Cheng, Woon, & Lynes, 2011).

In 1995, the top 3 most cited publications were all co-authored by Paul C. Stern, Gregory A. Guagnano, and Thomas Dietz, and presented advanced models of the attitude-behaviour relationship in the context of ERB. In the context of curbside recycling, a strong attitude-behaviour relationship was found, with Schwartz' (1977) norm-activation model and external conditions such as perceived cost predicting additional behaviours in households without a recycling bin (Guagnano, Stern, & Dietz, 1995). In a telephone study of general environmental beliefs, Stern et al (1995) found that values and beliefs (with values also predicting beliefs) predicted individuals' willingness to take environmental action, although a biospheric value-set could not be discerned within the sampled population, more broadly. In another empirical study examining

the relationship between the New Ecological Paradigm (NEP) Scale (Dunlap & Van Liere, 1978; 2000), the most frequently used measure of environmental concern, and the ascription of responsibility (AC) measure from Schwartz' (1977) norm-activation model, Stern et al (1995) found that these two measures produced indistinguishable results in terms of psychometrics and predicting behavioural intentions, but different somewhat in predicting basic value orientations. These works were integral in several prominent and still widely cited theories on ERB, including Stern's (2000) theory of environmentally significant behaviour, Schultz's (2001) three-factor structure of environmental concern, and Dunlap et al.'s (2000) revised NEP scale.

The biggest peak in the RPYS – and therefore the most important/influential year – was 2000. The list of the most cited articles (see Figure 7) from this year was dominated by articles from the 2000 JSI special issue; all 11 articles are in the top 25 articles most cited, and 9 are in the top 10 most cited. The top 3 most cited articles were Stern's "Toward a Coherent Theory of Environmentally Significant Behavior", Dunlap, Van Liere, Mertig, and Jones' "Measuring Endorsement of the New Ecological Paradigm: A Revised NEP Scale", and Zelezny, Chua, and Aldrich's "Elaborating on Gender Differences in Environmentalism". These articles pertained to core aspects of ERB from theoretical perspectives (Stern, Zelezny, Schultz), measurement (Dunlap et al), and promotion (De Young), including addressing the motivations and barriers of environmentalism (McKenzie-Mohr). The design and implementation of interventions to prompt voluntary ERBs draw heavily from this literature, as evident from research published in many disciplines such as management (e.g., Kim et al., 2017), climate change (e.g., Corner & Randall, 2011), energy policy (e.g., Hargreaves, Nye, & Burgess, 2010), and social marketing (e.g., Peattie & Peattie, 2009) citing articles from this special issue.

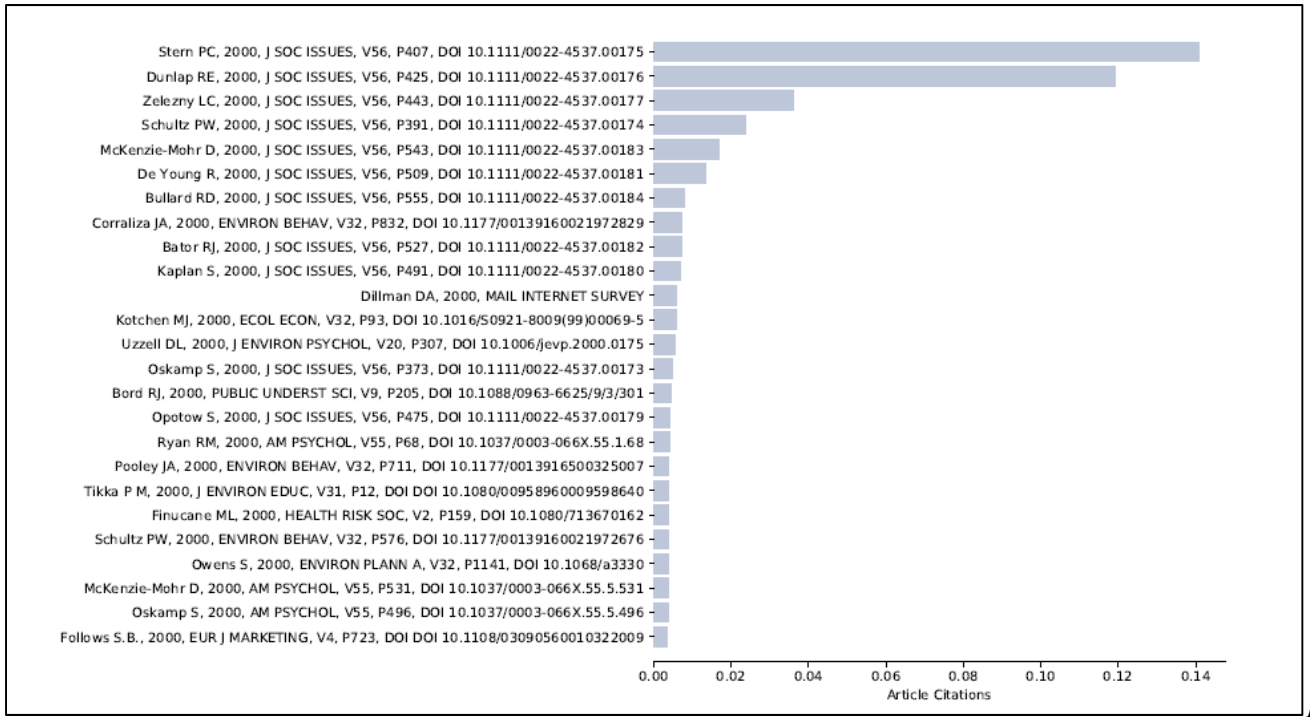

Figure 7: Top 25 citations from the year 2000

In 2009, the most cited publication was Steg & Vlek's article "Encouraging pro-environmental behaviour: An integrative review and research agenda," followed by Dietz et al.'s "Household actions can provide a behavioral wedge to rapidly reduce US carbon emissions" and Nisbet, Zelenski, and Murphy's "The Nature Relatedness Scale Linking Individuals' Connection With Nature to Environmental Concern and Behavior". In review of the contribution of environmental psychology to the field (including shortcomings), Steg & Vlek (2009) proposed a general four-set framework for promoting PEB: (1) identification of the behaviour to be changed, (2) examination of the main factors underlying this behaviour, (3) design and application of interventions to change behaviour to reduce environmental impact, and (4) evaluation of the effects of interventions. In a study of household actions in five distinct behavioural categories, Dietz et al. (2009) determined the most effective interventions to promote the desired behaviours without the use of new regulatory measures. Nisbet et al. (2009) proposed a new theoretical construct, Nature Relatedness (NR), and a scale to assess the affective, cognitive, and experiential aspects of individual connection to nature; in two empirical tests, NR was found to be correlated with environmental scales of behaviour, supporting the reliability and validity of NR as a method for investigating human-nature relationships.

The results from the standard RPYS analysis clearly established that 2000 was a very important/influential year in the development of research on ERB. In particular, the 2000 JSI special issue, was shown to be a collection of highly cited articles in this field of research (all of the articles from this special issue are in the top 25 most cited, and eight are in the top 10). To determine whether or not this influence has been consistent since the publication of that special issue, or if it is the result of either older or more recent scholarship, the analysis was extended using multi-RPYS. That is, a separate RPYS analysis was conducted for every year between 1960 and 2016. The results are presented in the form of a heatmap in Figure 8.

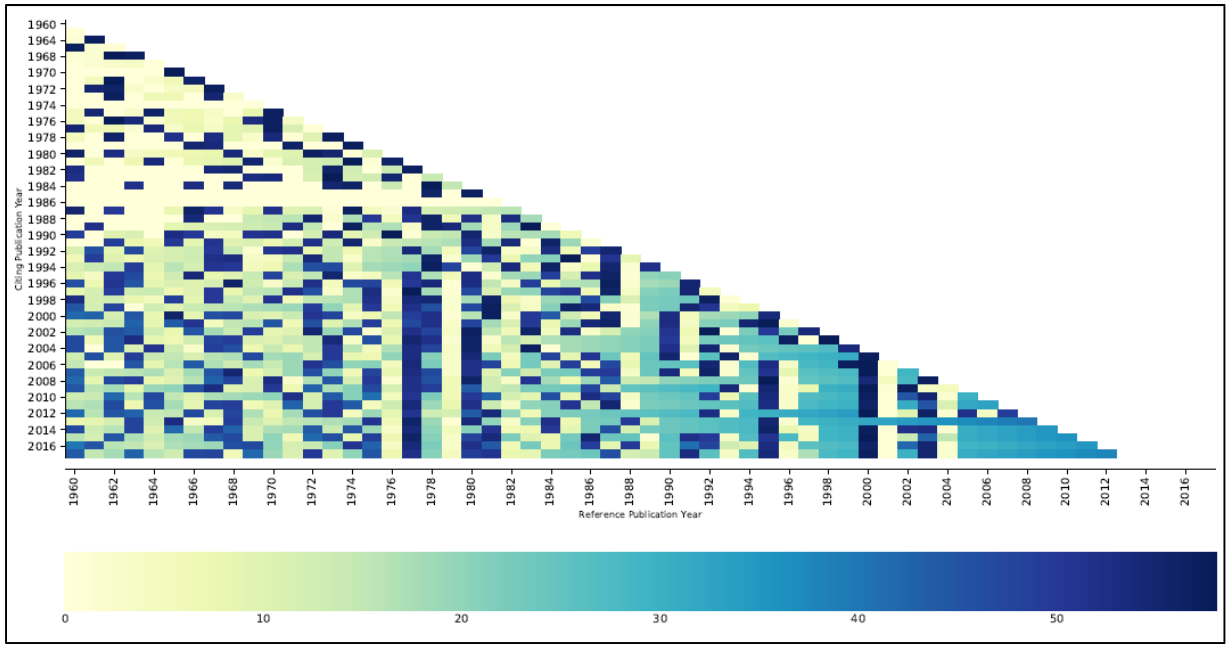

Figure 8: Multi-year RPYS for the 'environmentalism' literature

In this graph, the publication years for the articles in the ERB literature are on the Y axis, and the publication years of the books and articles they cite appear on the X axis. The legend indicates the number

of citations received (dark blue indicates 60+ citations). Darker cells indicate that a given year (e.g., 2000) was very important in research being conducted in another year (e.g. 2008). Lasting influence appears in this heatmap as dark columns spanning multiple years. Figure 8 has, as expected, dark columns for 1977 (beginning in 1994), 1980, 1995, and 2000. With the exception of a single year (2013), the JSI special issue has had a strong influence on publications in the field of ERB every year since it appeared.

2.4.2 Co-Citation Network Analysis

Having identified the 2000 JSI Vol 56 Issue 3 special issue as containing important/influential articles that have shaped the current structure of ERB research , the second goal was to identify, assess, and characterize any distinct research clusters in the field, and ascertain whether the clusters map onto the four themes of the special issue, as identified by the editors of the issue: Synthesis of literature to advance conceptual and theoretical frameworks (synthesis), explicit and implicit power and its relationships to environmental action and justice (power), motives and values that prompt action (motives/values), and real-life application of theories in effective and pragmatic strategies to promote PEB (applicability). The following sections provide the results of the co-citation analysis. Gephi version 0.9.2 was predominately used to analyze the network data. The data were also exported into Microsoft Excel for more granular analyses.

2.4.2.1 Basic Characteristics

The literature dataset consisted of 609 articles (individual nodes in the co-citation network, as per Section 3.2.1) from 180 different journals, although 55% of the articles were published in the top 20 journals, which each published six or more articles. The *Journal of Environmental Psychology (JEP)* was the leading journal by # of publications (15% of articles, n=91), by far. The next five journals were *Environment & Behavior* (10%, n=61), *Energy Policy* (5%, n=30), *Journal of Social Issues* (3%, n=16), and *Society & Natural Resources* (3%, n=16). The top 5 cited articles were: Stern's (2000) 'Toward a coherent theory of environmentally significant behavior' (1735 citations), Dunlap's (2000) 'Measuring endorsement of the new ecological paradigm: A revised NEP scale' (1461 citations), Steg's (2009) 'Encouraging pro-environmental behaviour: An integrative review and research agenda' (689 citations), Lorenzoni's (2007) 'Barriers perceived to engaging with climate change among the UK public and their policy implications' (584 citations), and Shove's (2010) 'Beyond the ABC: climate change policy and theories of social change' (543 citations). The top authors by number of first authored publications were Stewart Barr (12 papers), Taciano Milfont (9 papers), Florian Kaiser (8 papers), Jim DeGroot (7 papers), and Linda Steg (6 papers. The corresponding author's address was used to categorize the citing publications by country (8 of the 609 articles did not provide an address for the corresponding author). In total, 41 countries were identified. Approximately 66% of all articles were published in the top five countries: USA (35% of articles, n=216); United Kingdom (10%, n=63); Australia (9.0%, n=53); Netherlands (7%, n=40); Canada (5%, n=30). Approximately 82% of the articles were published in the top 10 countries. As per Gaede & Rowlands' network visualization of social acceptance research (2018), the growth of publications, broken down by the top five countries and the 'rest of the world' (ROW), is shown in Figure 9.

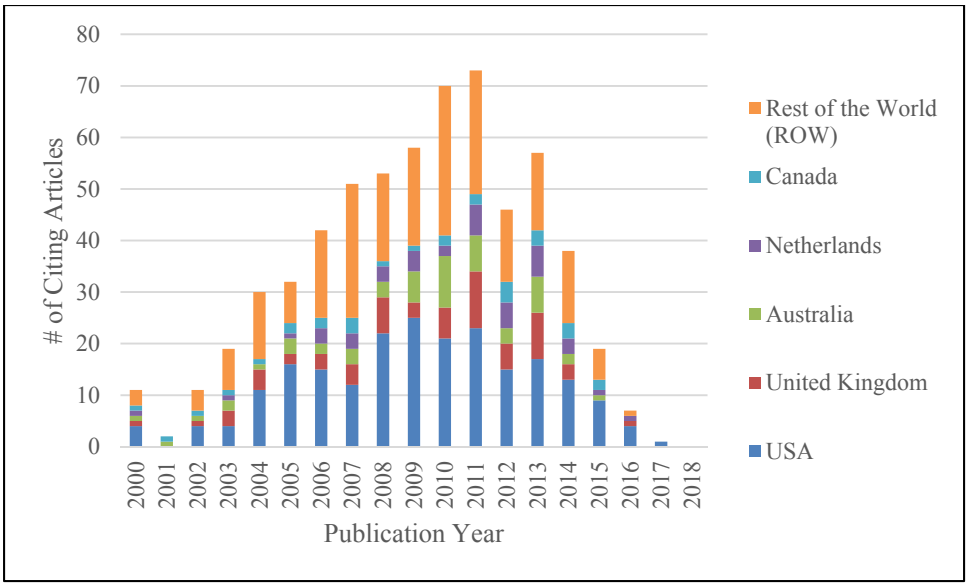

Figure 9: Citing Articles, per year and country of corresponding author

2.4.2.2 Research Clusters

The network analysis divided the 609 articles into six groups, as outlined in Table 2 and illustrated in Figure 10. The visualization of the co-citation network, produced in Gephi version 0.9.2, illustrates the six distinct groups or research clusters. The descriptive statistics are presented in Table 2, along with the most frequently used keywords (according to text analysis of author-defined keywords) and the main subjects studied, as deduced from first author review of the abstracts.

Table 2: Documents, citations, keywords, and main subject(s) of clusters in co-citation network

Cluster	# of documents	% of documents	No. of citations	% of citations	Top 5 Keywords[1] (by frequency)	Primary Theme Categorization from 2000 JSI special issue	Main Subject(s)
0	239	39%	19,261	41%	Proenvironmental behaviour Proenvironmental attitudes Climate Change Values Energy Conservation	• Synthesis	• Models/instruments/indicators • Theories of pro-environmental behaviour • Contributions of the field of psychology (current and potential)
1	56	9%	6,129	13%	Climate Change Global warming Environmental (behaviour, change, justice, policy, movement) Social (identity, orientation Risk/ Risk perceptions	• Applicability	• Knowledge operationalization • Outcome orientation/ promoting pro-environmental behaviour
2	137	22%	7,868	17%	New Ecological paradigm Environmental Attitudes Environmental Behaviour Conservation Tourism	• Synthesis	• Measuring and predicting pro-environmental values • Connectedness to nature and place attachment – construct validity
3	53	9%	4,625	10%	Environmental attitudes Ecological behaviour Nature (connectedness, interaction, place) Attitudes Conservation behaviour	• Combination: Synthesis, Motives/Values, Power	• Models of pro-environmental behaviour • Implications for public policy on climate change
4	75	12%	6,382	13%	Proenvironmental Behaviour Theory of Planned Behaviour Values Value-Belief-Norm Theory Social norms	• Motives/Values	• Measuring and predicting pro-environmental values • Connectedness to nature • Place-based, outdoor recreation, ecological ecosystems, tourism
5	43	7%	3,062	6%	Environmental behaviour Environmental concern Gender Social (capital, change, context, learning) Attitudes	• Power	• Gender, partisan, and sociodemographic differences in beliefs and behaviour • National and cross-national

[1]The frequency of occurrence of author-defined keywords (as opposed to those defined by Web of Science) was assessed using an online text analyzer. A sample of the analysis used for each cluster is provided in Appendix B.

Cluster 0 (coloured purple in Figure 10) is distinguished by its theoretical nature. All 239 articles in this cluster pertain to models, instruments, measures, indicators, characteristics, or perceptions that may promote or inhibit some form of pro-environmental behaviour. Cluster 0 also includes articles that discuss current and potential contributions of the field of psychology to pro-environmental behaviour change issues. Other theories, models or constructs included in the highest-ranking works (by citation and centrality) are: social practice theory, normative messaging, community-based social marketing (McKenzie-Mohr, 2000), and goal framing. Cluster 0 includes the top-cited paper in the network by Stern (2000): 'Toward a coherent theory of environmentally significant behavior'. Second is Steg & Vlek's (2009) integrative review of pro-environmental behaviour research. Third is Shove's provocative (self-labelled) paper (2010) which reflects on the restricted models and concepts of social change that are embedded in climate change policy in the UK, and globally. The top five keywords (by frequency) are: Pro-environmental Behaviour, Pro-environmental attitudes, Climate Change, Values, and Energy Conservation.

Cluster 1 (coloured blue in Figure 10) is distinguished by its outcomes-orientation, with focus on operationalizing knowledge in the promotion of pro-environmental behaviours. All 56 articles in this cluster pertain to the real-life application of models, instruments, or knowledge, in order to promote PEB. The top-cited paper in Cluster 1 is Verplanken's (2002) paper on value-congruent choices. Second is Dietz's (2005) review of the values construct in disciplinary studies on sustainable behaviour. Third is Steg's (2005) test of the Value-Belief-Norm (VBN) Theory in predicting energy policy acceptance. The top five keywords (by frequency) are: Climate Change, Global warming, Environmental (behaviour, change, justice, policy, movement), Social (identity, orientation, and Risk/ Risk perceptions.

Cluster 2 (coloured turquoise in Figure 10) is distinguished by its theoretical nature. All 137 articles in this cluster pertain to models, instruments, measures, indicators, characteristics, or perceptions that may promote or inhibit some form of pro-environmental behaviour. Other theories, models or constructs included in the highest-ranking works (by citation and centrality) are: connectedness to nature (Mayer and Frantz, 2004), attachment to place, consumerism, and environmentalism. Cluster 2 includes one of the 10 most cited works within the co-citation network, Schultz's (2000) 'Empathizing with nature: The effects of perspective taking on concern for environmental issues'. This article is also the highest ranked in the cluster in terms of citation count, betweenness and degree centrality. The second and third highest ranked articles, respectively, are Nisbet's (2009) paper which presents Nature Relatedness, a scale that assesses the affective, cognitive, and experiential aspects of individuals' connection to nature, and Hinds' (2008) paper which presents an extended model of Azjen's Theory of Planned Behaviour (TPB). The top five keywords (by frequency) are: New Ecological Paradigm, Environmental Attitudes, Environmental Behaviour, Conservation, and Tourism.

Cluster 3 (coloured pink in Figure 10) contains articles spanning three of the four themes. The highest-cited article is Zelezny et al's (2000) paper on gender differences in environmentalism. Second is Hunter's (2004) paper on cross-national gender variation in environmental behaviours. Third is Franzen's (2010) paper on cross-national determinants of environmental concern. The main characteristic of this cluster is its emphasis on the application of pro-environmental models and/or measurements of pro-environmental characteristics on the development of public policy frameworks to address climate change (from local to global level). Similar to Cluster 1, this Cluster included fundamental theoretical constructs such as environmental

attitudes, the attitude-behaviour gap, but from the public goods perspective. For example, the determinants of public concern for the environment, consumers' willingness to pay to address environmental issues, and trade-offs between ecosystem services and economic gains were topics covered. The top five keywords (by frequency) are: Environmental attitudes, Ecological behaviour, Nature (connectedness, interaction, place), Attitudes, and Conservation behaviour.

Cluster 4 (coloured green in Figure 10) is distinguished by its focus on motivations and values. The highest cited article is Dunlap and Van Liere's (2000) New Ecological Paradigm (NEP) Scale, a revision of their widely used measure of pro-environmental behaviour orientation, the New Environmental Paradigm (NEP) Scale, which was published in 1978. Second is Miller's (2005) paper on biodiversity loss. Third is Brown's (2007) paper on the relationship between place attachment and landscape values. The top five keywords (by frequency) are: Pro-environmental Behaviour, Theory of Planned Behaviour, Values, Value-Belief-Norm Theory, and Social norms.

Cluster 5 (coloured orange in Figure 10) is distinguished by its focus on power. The highest-cited is Lorenzoni's (2007) paper on the barriers for climate change action in the UK. Third is Whitmarsh's (2010) paper on the role pro-environmental self-identity in determining consistency across diverse pro-environmental behaviours. This cluster is distinguished by its focus on public perception and the communication of the risks of climate change and the actions needed to mitigate and adapt to climate change. Similar to Cluster 1, this cluster includes many articles that make recommendations for public policy, with more emphasis on the misconceptions about behaviour change that are embedded in existing strategies, and the need for media communication and marketing interventions to include a deeper level of understanding about the determinants of environmental behaviour. The top five keywords (by frequency) are: Environmental behaviour, Environmental concern, Gender, Social (capital, change, context, learning), and Attitudes.

Overall, the network appears to be very dense, with a lobed structure, as can be seen in Figure 10. The two largest clusters (0 and 4) form the two lobes, with the papers from the JSI 2000 special issue written by Stern and Dunlap & Van Liere, respectively, being the most central within the network as a whole and within their clusters. This indicates that the authors have had significant impact on the field, parallel to how citation count of a paper indicates the impact of an author (Yan & Ding, 2009).

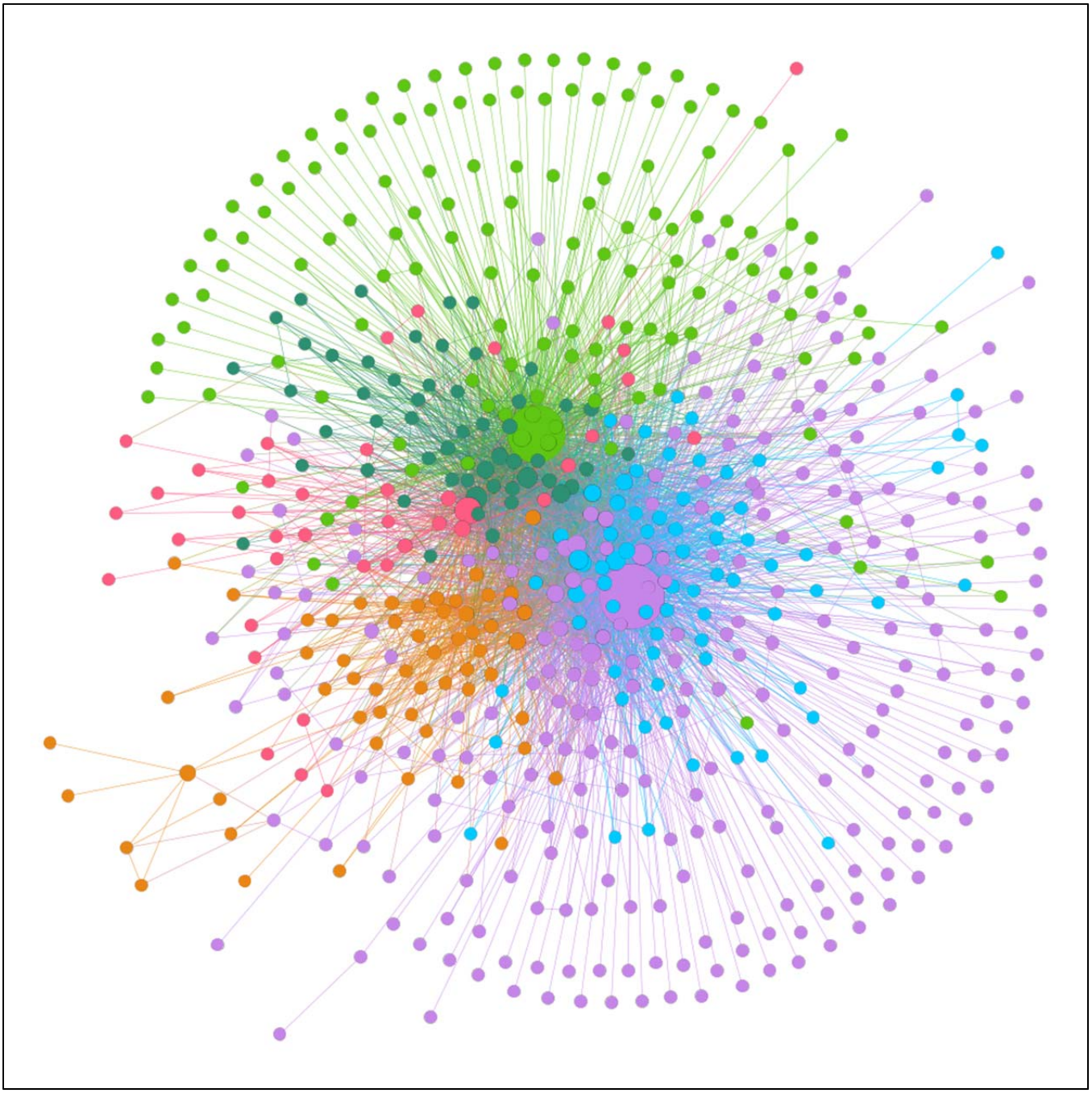

Figure 10: Co-citation network (metaknowledge)

2.4.2.3 Centrality Measures

In order to understand the importance of the articles in the co-citation network, the top 20 papers for various centrality characteristics were assessed – betweenness, closeness, eigenvector, and degree (see Table 3), as each metric provides a different interpretation of the influence of an article. Betweenness centrality measures the extent to which a point in a network acts as a 'broker' or 'gatekeeper' of the flow of information (Fursov & Kadyrova, 2017; Scott, 2013). In this case, articles with high betweenness centrality can be interpreted as bridging other articles within a cluster (or even bridging clusters within the broader network) by

"consolidating accumulated theoretical or practical experience" (Fursov & Kadyrova, 2017, p. 1950). As such, betweenness centrality will be the focus of this analysis, and this aligns most closely with the research objectives and has been applied in other recent bibliometric analyses of energy-related citation networks (e.g., Gaede & Rowlands, 2018). The other commonly used centrality measures such closeness and degree centrality are considered to provide additional descriptive characteristics of the most central papers. For example, closeness centrality measures the distance of a node to all other nodes (Scott, 2013). An article is globally central within a cluster and/or the broader network if it lies at short distances from many other points. Degree centrality measures the number of connections that a node has with other nodes in the network. Generally, articles with higher degree centrality are central to the structure of the network, and therefore are more influential (Yan & Ding, 2009). Eigenvector centrality is based on the premise that nodes that are connected to highly connected nodes are more central – it is calculated by assigning relative scores to all nodes in a network such connections to high-scoring nodes are weighted more highly than equal connections to low-scoring nodes (Parand, Rahimi, & Gorzin, 2016). For a comprehensive analysis on the application of centrality measures to publication impact analysis, refer to Yan and Ding (2009).

Of the special issue articles, Stern, Dunlap & Van Liere, McKenzie-Mohr, and DeYoung ranked highly according to all four measures of centrality, and Bullard was ranked in the top 20 according to betweenness centrality. Schultz and Zelezny et al. ranked in top 3 within their respective clusters for all four measures of centrality, but did not rank in the top 20, in the overall network.

In general, the papers within the six clusters rank similarly between the four measures of centrality. Stern and Dunlap's articles from the special issue are the furthest outliers in the graphs of partition – centralities (bottom row of Figure 11), followed by Steg & Vlek's (2009) article. When examining each cluster individually, the impact of the highest cited special issue articles is reinforced.

In Cluster 0, Stern's paper is the most central, according to all four measures. Steg & Vlek's (2009) paper ranks second in all 4 measures of centrality. The rankings for third differ by measure: McKenzie-Mohr's paper on Community-Based Social Marketing (special issue) by betweenness centrality, Poortinga's (2004) paper on value judgements and quality of life in explaining household energy use by closeness, eigenvector and degree centrality. The two top-ranked papers are also co-cited the most frequently in this cluster, 117 times. Given that Steg & Vlek's paper is an integrative review of research on pro-environmental behaviour change, in which Stern's theory is prominent, this is not surprising. Four other papers from the JSI special issue (by Bator, Clayton, DeYoung, and Opotow) are in Cluster 0.

In Cluster 1, 89% of the papers (n=50) were published between 2005 and 2016. There are no papers from the JSI special issue in Cluster 1. The highest ranked articles differ by measure of centrality. Garvill's (2003) paper on travel choice is ranked highest by between centrality, followed by Collins' (2007) paper on predicting commuter transport mode choice, and Klockner's (2009) paper on personal norms of purchasing organic milk (alo ranked third according to closeness and degree centrality). Raymond's (2016) article on the valuation of ecosystem services ranks highest by closeness and eigenvector centrality, followed by Kallbekken's (2011) article on public acceptance of environmental taxes. The ranking of these two papers is

reversed for degree centrality. Han's (2015) paper on norm activation in the lodging context is ranked third according to eigenvector centrality.

In Cluster 2, three of Schultz's papers are the most central according to all four measures of centrality. Schultz's (2000) paper from the JSI special issue on empathizing with nature is ranked highest by betweenness centrality (third by closeness and degree centrality), followed by his (2005) paper on values related to environmental concern and environmental behaviour (first by closeness, eigenvector and degree centrality), and his (2001) paper on the structure of environmental concern (second by closeness, eigenvector and degree centrality). Schultz's (2004) paper on implicit connections to nature ranked third according to eigenvector centrality. There are no other papers from the JSI special issue in Cluster 2.

In Cluster 3, Zelezny et al's paper on gender differences in environmentalism ranks is the most central according to all measures of centrality, followed by Hunter's (2004) paper on cross-national gender variation in environmental behaviours. Dietz's (2002) paper on gender, values and environmentalism ranks third by closeness and degree centrality, while Urien's (2011) paper on the influence of generativity and self-enhancement values on ERB ranks third by betweenness centrality, and Cottrell's (2003) paper on the influence of sociodemographics and attitudes on the environmental behaviour of recreational boaters ranks third by eigenvector centrality. There are no other papers from the JSI special issue in Cluster 3.

In Cluster 4, Dunlap & Van Liere's (2000) paper from the JSI special issue on the New Ecological Paradigm (NEP) scale is the most central according to degree, eigenvector, and closeness centrality. Dunlap's (2008) paper on the development and worldwide use of the NEP scale ranks second by all measures of centrality. The rankings for third differ by measure: Halpenny's (2010) paper on the effect of place attachement on the PEB of park visitors ranks third by betweenness centrality, and Hawcroft's (2010) paper presenting a meta-analysis of the use of the NEP scale ranks third by closeness, eigenvector, and degree centrality. There are no other papers from the JSI special issue in Cluster 4.

In Cluster 5, Gifford's (2011) paper on the psychological barriers (dragons of inaction) that limit climate change mitigation and adaption is the most central according to betweenness and eigenvectorcentrality (second by closeness and degree centrality). Lorenzoni's (2007) paper on perceived barriers to engaging with climate change in the UK context ranks first by closeness and degree centrality (second by eigenvector centrality). Bullard's (2000) papers on the impact of grassroots activism on public policy making from the JSI special issue ranked second by betweenness centrality. Swim's (2011) paper on psychology's contribution to understanding and addressing climate change and Whitmarsh's (2009) paper on the risk perception and behavioural response of flood victims ranked third by betweenness and closeness centrality, respectively. There are no other papers from the JSI special issue in Cluster 5.

Table 3: Top 20 authors based on centrality measures

Rank	Author	Between-ness	Author	closeness	Author	Eigenvector	Author	degree
1	Stern Pc, 2000, J SOC ISSUES	0.52270	Stern Pc, 2000, J SOC ISSUES	0.84444	Stern Pc, 2000, J SOC ISSUES	0.26630	Stern Pc, 2000, J SOC ISSUES	0.82072
2	Dunlap Re, 2000, J SOC ISSUES	0.32056	Dunlap Re, 2000, J SOC ISSUES	0.59842	Dunlap Re, 2000, J SOC ISSUES	0.24928	Dunlap Re, 2000, J SOC ISSUES	0.66776
3	Steg L, 2009, J ENVIRON PSYCHOL	0.04065	Steg L, 2009, J ENVIRON PSYCHOL	0.54044	Steg L, 2009, J ENVIRON PSYCHOL	0.19325	Steg L, 2009, J ENVIRON PSYCHOL	0.34210
4	Gifford R, 2011, AM PSYCHOL	0.00890	Poortinga W, 2004, ENVIRON BEHAV	0.53380	Poortinga W, 2004, ENVIRON BEHAV	0.14098	Poortinga W, 2004, ENVIRON BEHAV	0.17434
5	Mckenzie-Mohr D, 2000, J SOC ISSUES	0.00878	Gatersleben B, 2002, ENVIRON BEHAV	0.52504	Gatersleben B, 2002, ENVIRON BEHAV	0.12920	Gatersleben B, 2002, ENVIRON BEHAV	0.14638
6	Bullard Rd, 2000, J SOC ISSUES	0.00722	Lorenzoni I, 2007, GLOBAL ENVIRON CHANG	0.52504	Clark Cf, 2003, J ENVIRON PSYCHOL	0.11170	Clark Cf, 2003, J ENVIRON PSYCHOL	0.11842
7	Castro P, 2012, POLIT PSYCHOL	0.00701	Gifford R, 2011, AM PSYCHOL	0.52368	De Young R, 2000, J SOC ISSUES	0.10996	Lorenzoni I, 2007, GLOBAL ENVIRON CHANG	0.11842
8	Swim Jk, 2011, AM PSYCHOL	0.00651	De Young R, 2000, J SOC ISSUES	0.51788	Lindenberg S, 2007, J SOC ISSUES	0.10941	De Young R, 2000, J SOC ISSUES	0.11677
9	De Young R, 2000, J SOC ISSUES	0.00537	Lindenberg S, 2007, J SOC ISSUES	0.51525	Dunlap Re, 2008, J ENVIRON EDUC	0.10136	Lindenberg S, 2007, J SOC ISSUES	0.11513
10	Dunlap Re, 2008, J ENVIRON EDUC	0.00452	Clark Cf, 2003, J ENVIRON PSYCHOL	0.51438	Gifford R, 2011, AM PSYCHOL	0.09665	Dunlap Re, 2008, J ENVIRON EDUC	0.11513
11	Shove E, 2010, ENVIRON PLANN A	0.00423	Dunlap Re, 2008, J ENVIRON EDUC	0.51178	Lorenzoni I, 2007, GLOBAL ENVIRON CHANG	0.09605	Gifford R, 2011, AM PSYCHOL	0.10855
12	Poortinga W, 2004, ENVIRON BEHAV	0.00415	Whitmarsh L, 2009, J ENVIRON PSYCHOL	0.50666	Whitmarsh L, 2009, J ENVIRON PSYCHOL	0.09341	Whitmarsh L, 2009, J ENVIRON PSYCHOL	0.10361
13	Lorenzoni I, 2007, GLOBAL ENVIRON CHANG	0.00407	Mckenzie-Mohr D, 2000, J SOC ISSUES	0.50414	Hawcroft Lj, 2010, J ENVIRON PSYCHOL	0.08392	Hawcroft Lj, 2010, J ENVIRON PSYCHOL	0.09375
14	Sidique Sf, 2010, RESOUR CONSERV RECY	0.00392	Hawcroft Lj, 2010, J ENVIRON PSYCHOL	0.50414	Barr S, 2007, ENVIRON BEHAV	0.08353	Mckenzie-Mohr D, 2000, J SOC ISSUES	0.09210
15	Halpenny Ea, 2010, J ENVIRON PSYCHOL	0.00363	Abrahamse W, 2007, J ENVIRON PSYCHOL	0.50414	Abrahamse W, 2007, J ENVIRON PSYCHOL	0.08321	Abrahamse W, 2007, J ENVIRON PSYCHOL	0.09046
16	Arbuckle Jg, 2013, CLIMATIC CHANGE	0.00333	Cialdini Rb, 2003, CURR DIR PSYCHOL SCI	0.50372	Mckenzie-Mohr D, 2000, J SOC ISSUES	0.08207	Dietz T, 2007, RURAL SOCIOL	0.08059
17	Knight At, 2008, CONSERV BIOL	0.00328	Swim Jk, 2011, AM PSYCHOL	0.50165	Cialdini Rb, 2003, CURR DIR PSYCHOL SCI	0.07899	Swim Jk, 2011, AM PSYCHOL	0.07730
18	Whitmarsh L, 2009, J ENVIRON PSYCHOL	0.00285	Dietz T, 2007, RURAL SOCIOL	0.50082	Slimak Mw, 2006, RISK ANAL	0.07753	Cialdini Rb, 2003, CURR DIR PSYCHOL SCI	0.07565
19	Feygina I, 2010, PERS SOC PSYCHOL B	0.00270	Whitmarsh L, 2011, GLOBAL ENVIRON CHANG	0.50041	Johnson Cy, 2004, ENVIRON BEHAV	0.07164	Slimak Mw, 2006, RISK ANAL	0.07401
20	Hawcroft Lj, 2010, J ENVIRON PSYCHOL	0.00267	Barr S, 2007, ENVIRON BEHAV	0.50029	Dietz T, 2007, RURAL SOCIOL	0.06930	Barr S, 2007, ENVIRON BEHAV	0.07236

*Articles from the JSI 2000 have been highlighted.

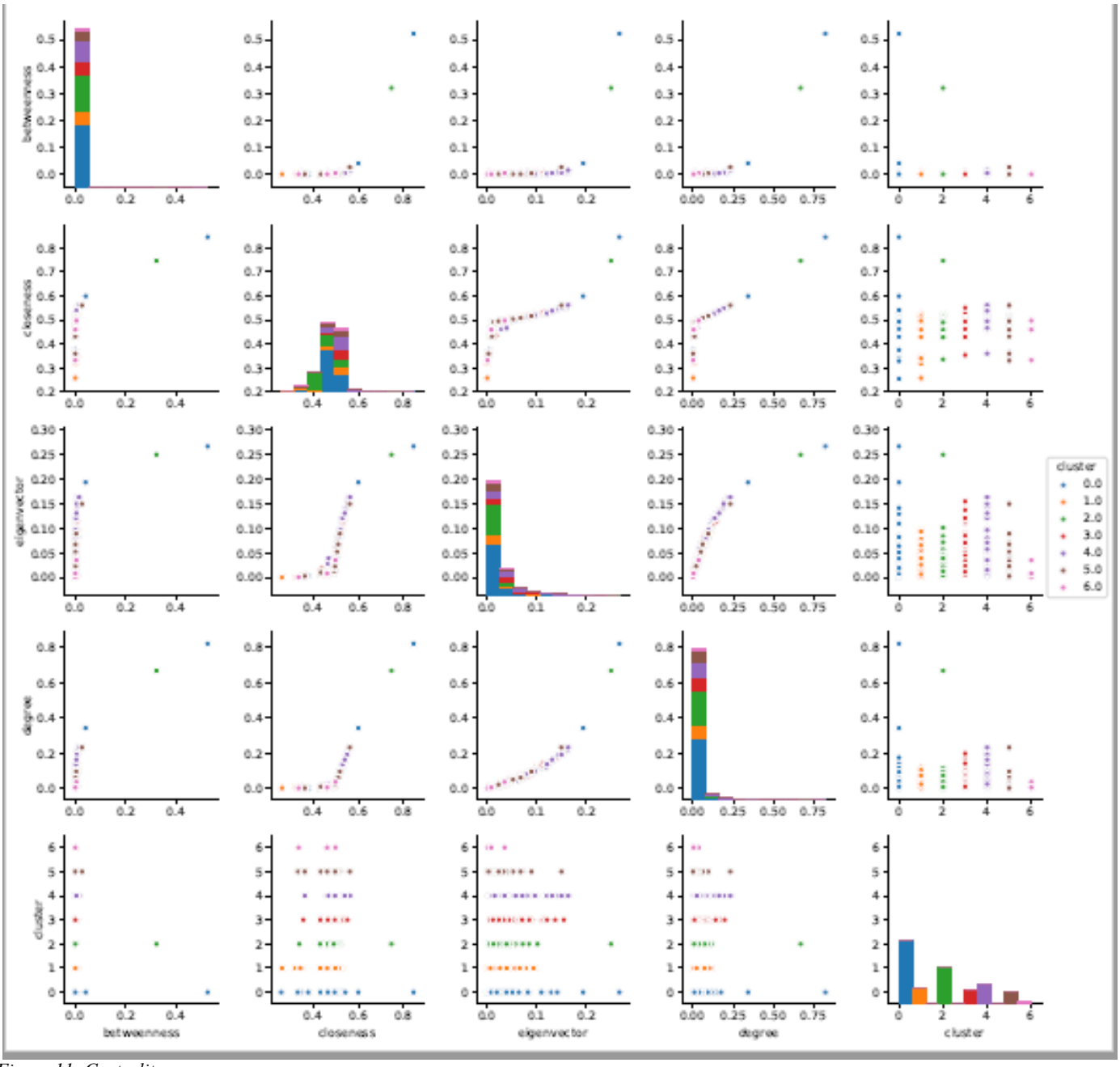

Figure 11: Centrality measures

2.4.3 Bibliometric Coupling

The basic characteristics are presented for the bibliometric coupling network, primarily to maintain consistency with the prior section. Recall from Section 3.3 that the overall network structure produced using this method is coarse. The value of using this tool is in the assessment of the research clusters.

2.4.3.1 Basic Characteristics

The literature dataset consisted of 1,143 articles from 343 different journals, although 66% of the articles were published in the top 61 journals, which each published four or more articles. The *Journal of*

Environmental Psychology (JEP) was the leading journal by # of publications (9% of articles), by far. The next five journals were *Environment & Behavior* (6%), Energy Policy (3%), *Society & Natural Resources* (2.4%), *Global Environmental Change-Human and Policy Dimensions* (2.2%), and *Journal of Cleaner Production* (2.1%). Overall, 52% of all articles were found in the top 30 journals, which each published 8 or more articles. The top 5 cited articles were: Stern's (2000) paper (1681 citations[12]), n1564 (1418), n1314 (656), n1420 (567), and n1565 (409). The top four authors by total publications were Barr, S. (18), Steg, L. (17), Han, H. (14), and Fielding, KS (13). The top four authors by 'first author' publications were: Barr, S. (17); Han, H. (13); Kaiser, FG. (9); and Milfont, TL. (9). The articles were contributed by 773 unique first authors, 174 (22.5%) of which were first author on two or more papers.

We used the corresponding author's address to categorize the citing publications by country (11 of the 1143 articles did not provide an address for the corresponding author). In total, 53 countries were identified. Approximately 57% of all articles where published in the top five countries: USA (29.7% of articles); UK (9.3%); Australia (8.5%); Netherlands (7.1%); Sweden (4.8%). Canada was the sixth ranked country by number of publications (4.2%). Approximately 82% of the articles were published in the top 15 countries.

2.4.3.2 Research Clusters

The top 9 communities (by size) comprised 64% of the publications (as opposed to the previously described approach where the five clusters included 100% of the publications).

[12] The number of citations for the same article differs between the two networks, due to when the dataset was downloaded from Web of Science. The dataset for the edges=10 analysis was downloaded in January 2018, while the dataset for the link sparisification was downloaded in April 2018, resulting in a higher number of citations in the latter set.

Table 4: Documents, citations, keywords, top journals, authors, and main subject(s) of clusters in bibliographic coupling network

Cluster	No. of documents	% of documents	No. of citations	% of citations	Top 5 Keywords (by frequency)	Top Journals (by publications)	Top Authors (by # of papers)	Main Subject(s)
0	188	16%	5,796	19%	pro-environmental behaviour climate change energy conservation behaviour change energy efficiency theory of planned behaviour	Energy Policy (20) Journal of Environmental Psychology (17) Environment & Behavior (14) Energy Research & Social Science (12)	Steg, L (3) Gifford, R (4) Ardoin, NM Thogersen, J	psychological models/ climate change/ reviews
1	167	15%	8,585	28%	pro-environmental behaviour environmental concern environmental values/orientation Value-Belief-Norm (theory) environmental attitudes personal norms	Journal of Environmental Psychology (26) Environment & Behavior (12) Journal of Applied Psychology (6) Society & Natural Resources (6)	Steg, L DeGroot, J Matti, S Dietz, T	social psychology/ values/ norms
2	129	11%	2,272	7%	sustainable consumption consumer behaviour willingness-to-pay environmental concern green marketing	International Journal of Consumer Studies (10) Journal of Business Research (9) Journal of Cleaner Production (9) Psychology & Marketing (8)	Nguyen, TN Lobo, A Wang, YF Greenland, S	green consumerism/ personal determinants/ norms
3	95	8%	4,105	13%	New Ecological Paradigm (NEP) (scale) scale (environmental/ecological) environmental attitudes environmental concern pro-environmental behaviour	Environment & Behaviour (13) Journal of Environmental Psychology (9) Journal of Environmental Education (6) Organization & Environment (5)	Milfont, TL Choi, AS Boeve-de-Pauw, J	NEP Scale/ environmental attitudes/ structures and tests
4	91	8%	4,209	14%	climate change risk (perception/ policy/ communication) global warming pro-environmental behaviour public (opinion/ attitudes/ perception/ engagement) social norms (incl. conflict)	Global Environmental Change-Human and Policy Dimensions (11) Journal of Environmental Psychology (9) Climate Policy (4) Environment & Behavior (4)	Whitmarsh, L Tranter, B Vedlitz, A Fielding, KS	climate change/ behavioral responses/ policy implications
5	88	8%	1,426	5%	pro-environmental behaviour Theory of Planned Behaviour Value-Belief-Norm (Theory) Norm activation (theory/ model) norms (personal/ moral/ social)	Journal of Environmental Psychology (14) Tourism Management (5) Journal of Travel & Tourism Marketing (4)	Han, H Klockner, CA Nayum, A Hwang, J	contextual influences/ application of models/ habits/

Cluster	No. of documents	% of documents	No. of citations	% of citations	Top 5 Keywords (by frequency)	Top Journals (by publications)	Top Authors (by # of papers)	Main Subject(s)
6	60	5%	2,177	7%	pro-environmental behaviour social practice theory sustainable consumption social norms/ lifestyles/ culture conceptual framework environmental attitudes/ climate	Resources, Conservation and Recycling (11) Ecological Economics (4) Journal of Environmental Planning and Management (3) Environment & Behavior (3) Applied Geography (3)	Barr, S Gilg, A Shaw, G Hargreaves, T Hansmann, R	consumer behaviour (mainly household)/ social practice theory/ lifestyles
7	48	4%	932	3%	environmental concern willingness-to-pay political orientation post materialism policy (public/ environmental)	Environmental Politics (3) Journal of Environmental Psychology (3) Social Indicators Research (3)	Mostafa, MM Marquatt-Pyatt, ST Chen, XD Peterson, MN	global perspectives/ multi-dimensional analyses/ societal outcomes
8	48	4%	1,510	5%	place attachment environmentally responsible behavior environmental attitudes renewable energy climate change	Society & Natural Resources (5) Journal of Sustainable Tourism (4) Tourism Management (4)	Devine-Wright, P Peterson, MN Jan, FH Liu, JG Krannich, RS	societal values/ valuing nature

For each group, we looked at the publication years, journals, and types (i.e., article or review), top papers (by global citations and betweenness centrality), and top authors (by authored works). Content analysis of the research front groupings was conducted by looking at keyword usage, both in terms of the most commonly used keywords and the co-occurrence of keywords. Analysis of keyword co-occurrence provides a matrix visualization, allowing us to see not only the most commonly used keywords, but also the likelihood that two terms are used together. Figure 12 shows the highest ranking articles by betweenness centrality, per community, with darker lines representing stronger connections. A full network visualization is presented in Appendix C.

There were 494 unique keywords used in community 0 (C0) (coloured purple in Figure 12). The top keywords (by frequency of use) were pro-environmental behaviour, climate change, energy conservation, behaviour change, energy efficiency, and Theory of Planned Behaviour (TPB). The strongest connections in the co-occurrence matrix were between the terms pro-environmental behavior (top-ranked) and sustainability, pro-environmental behaviour and conservation, and attitudes and behaviour. We will refer to this group as the psychological models/climate change group, and it is coloured purple in the network visualization.

There were 389 unique keywords used in community 1 (C1) (coloured blue in Figure 12). The top keywords (by frequency of use) were pro-environmental behaviour, environmental concern, environmental values/orientation, Value-Belief-Norm (theory), environmental attitudes, and personal norms. The strongest connections in the co-occurrence matrix were between the terms environmental concern and values, environment and values, and pro-environmental behaviour and values. We will refer to this group as the social psychology/values/norms group, and it is coloured blue in the network visualization.

There were 356 unique keywords used in community 2 (C2) (coloured green in Figure 12). The top keywords (by frequency of use) were sustainable consumption, consumer behaviour, willingness-to-pay, environmental concern, and green marketing. The strongest connection in the co-occurrence matrix is between the two terms: environmental marketing and green marketing. We will refer to this group as the green consumerism/personal determinants group, and it is coloured green in the network visualization.

There were 239 unique keywords used in community 3 (C3) (coloured black in Figure 12). The top keywords (by frequency of use) were New Ecological Paradigm (NEP) (scale), scale (environmental/ecological), environmental attitudes, environmental concern, and pro-environmental behaviour. The strongest connection in the co-occurrence matrix is between the two top ranked terms: NEP Scale and environmental attitudes. We will refer to this group as the NEP Scale/environmental attitudes group, and it is coloured black in the network visualization.

There were 233 unique keywords used in community 4 (C4) (coloured orange in Figure 12). The top keywords (by frequency of use) were climate change, risk (perception/ policy/ communication), global warming, pro-environmental behaviour, public (opinion/ attitudes/ perception/ engagement), social norms (incl. conflict). The strongest connections in the co-occurrence matrix is between the two top ranked terms:

global warming and climate change, and climate change and risk perception. We will refer to this group as the climate change/behavioural responses group, and it is coloured orange in the network visualization.

There were 264 unique keywords used in community 5 (C5) (coloured pink in Figure 12). The top keywords (by frequency of use) were pro-environmental behaviour, Theory of Planned Behaviour (TPB), Value-Belief-Norm (Theory), Norm activation (theory/ model), norms (personal/ moral/ social). The strongest connections in the co-occurrence matrix were between the two top ranked terms: environmental behavior and TPB, and human dimensions and environmental behaviour. We will refer to this group as the contextual influences/ application of models/ habits/ group, and it is coloured pink in the network visualization.

There were 186 unique keywords used in community 6 (C6) (coloured teal in Figure 12). The top keywords (by frequency of use) were pro-environmental behaviour, social practice theory, sustainable consumption, social norms/ lifestyles/ culture, conceptual framework, environmental attitudes/ climate. In this group, all of the connections in the co-occurrence matrix were of equal strength (n=2). We will refer to this group as the consumer behaviour (mainly household)/ social practice theory/ lifestyles group, and it is coloured teal in the network visualization.

There were 128 unique keywords used in community 7 (C7) (coloured yellow in Figure 12). The top keywords (by frequency of use) were environmental concern, willingness-to-pay, political orientation, post materialism, policy (public/ environmental). In this group, there were several connections in the co-occurrence matrix of equal strength (n=3), between the high ranked term post-materialism and the terms political orientation, locus of control, and global warming. There were several other connections of equal strength between other terms. We will refer to this group as the global perspectives/ multi-dimensional analyses/ societal outcomes group, and it is coloured yellow in the network visualization.

There were 159 unique keywords used in community 8 (C8) (coloured red in Figure 12). The top keywords (by frequency of use) were place attachment, environmentally responsible behavior, environmental attitudes, renewable energy, and climate change. The strongest connections in the co-occurrence matrix is between the top ranked terms: place attachment and climate change, and place attachment and environmentally responsible behaviour. We will refer to this group as the societal values/ valuing nature group, and it is coloured red in the network visualization.

Generally, the network appears to be even more dense, as seen in Figure 12, than the lobed structure of the network presented in the previous section.

In order to understand the influence of the authors within the network, a visualization was created of the highest-ranked papers by betweenness centrality in each cluster. As can be seen in Figure 12, there are strong connections within Clusters 0 and 3, and between Clusters 0 and 2.

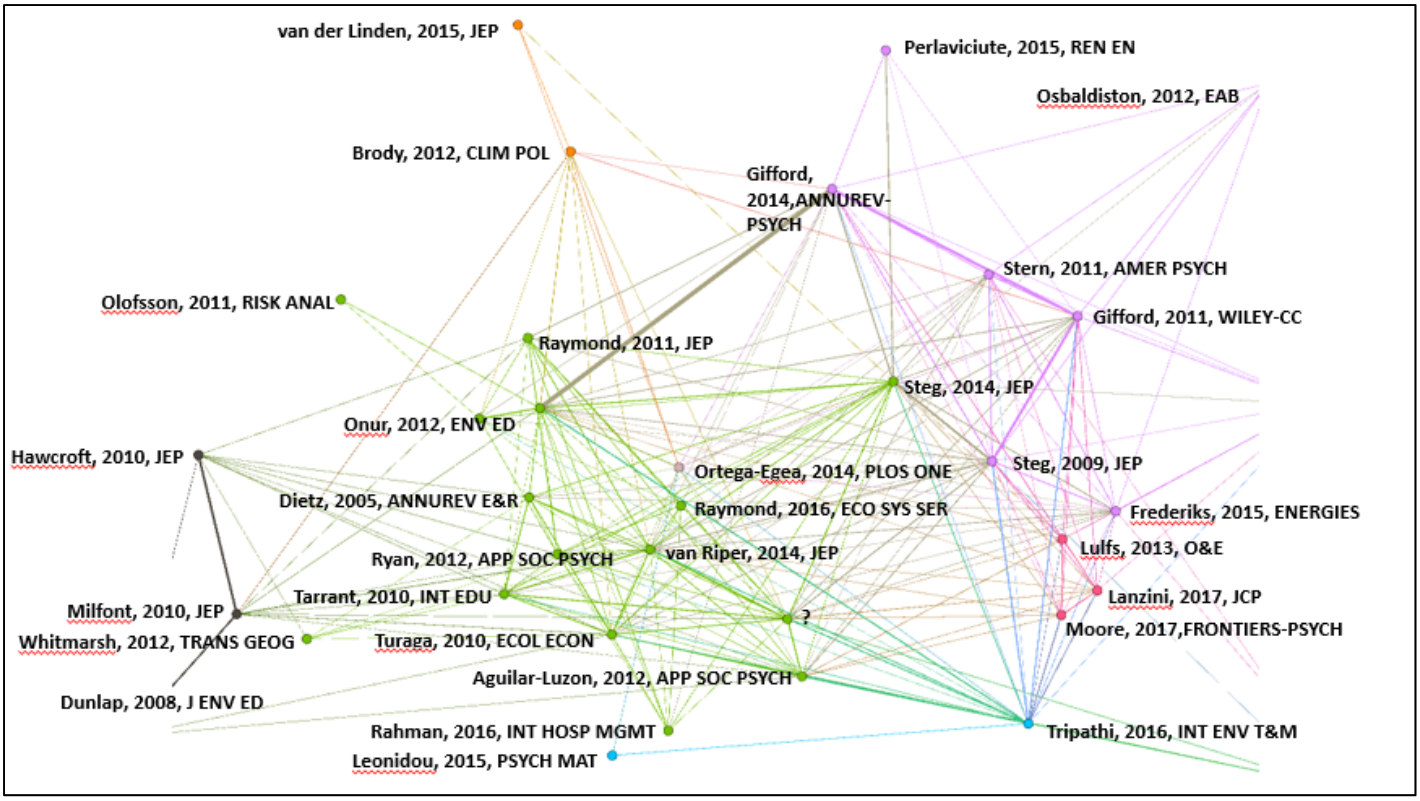

Figure 12: Highest-ranked articles per cluster, by betweenness centrality

2.5 Discussion

2.5.1 Differences in methodological approaches to network analysis

Bibliometric methods are gaining prominence in the analysis of information networks (McLevey & McIlroy-Young, 2017; Zupic & Čater, 2015). Two methods of analysis have been utilized in this study, co-citation analysis and bibliographic coupling. Several others, including (but not limited to) co-authorship analysis, keyword coupling and fuzzy logic have not been utilized, although it is recognized that these methods could have been used to investigate the research questions. Mapping and clustering analysis technique are complementary and various approaches can be used to combine these techniques to satisfactorily answer research questions regarding network analysis (Waltman et al., 2010). However, researchers must ensure that the underlying assumptions of techniques that are to be combined are understood, so that subjective decisions regarding methodological approaches (e.g., when to set a threshold and how high) are made appropriately (Waltman et al., 2010).

2.5.2 Basic characteristics

Despite the obvious differences in network structure, the basic network characteristics between the co-citation and bibliographic networks were similar. The top four countries by number of publications were the same, except that Australia and Netherlands switched places for third and fourth position. In the co-citation network, Canada ranked fifth (Sweden was 6th) and in the bibliographic coupling network, it was the opposite. The *Journal of Environmental Psychology* is by far the most influential journal across this field, followed by *Environment & Behavior*, in both analyses. The keyword analysis in both cases suggests that,

broadly speaking, the field is focused on pro-environmental behaviour, environmental concern, climate change, and environmental attitudes, though from a resource perspective, energy efficiency and energy conservation are most salient environmental issue (in terms of keyword frequency).

2.5.3 Network Structure - Influence

Looking at the visualization of the co-citation network, it seems that largest cluster, cluster 0 is the most influential, being both concentrated in the core and expanding widely. This cluster is highly theoretical, with papers focused on the models, instruments, and frameworks of environmental behaviour change theory and the disciplinary contributions of the psychology to achieve environmental outcomes, such as climate change mitigation and adaptation. The second largest and most influential cluster, cluster 4, focused on predicting environmental behaviour based on measuring environmental concern, with emphasis on ecological ecosystems and Cluster 2 is dominated by the work of Wesley Schultz, whose research focuses on the structure of environmental concern and connectedness to nature. The most influential cluster, Cluster 3, focused on the implications of empirical research on behaviour change for climate change policy, with emphasis on scales that measure pro-environmental behaviour in various contexts. The influence of the JSI special issue is evident, with five articles amongst the top-ranked by all betweenness, closeness, degree and eigenvector centrality. The strong connection between Clusters 0 and 4, through the articles by Stern and Dunlap & Van Liere suggest that behaviour change theory and measurement of pro-environmental behaviour are deeply related and are structurally integrated in the field of ERB research. It is interesting to note that while Elizabeth Shove's article on the lack of social practice theory in climate change policy is one of the top cited papers, it did not rankly highly based on any measure of centrality. This suggests that the social practice theory may be an emerging topic of interest within the field, but this paper has not yet become an influential paper in the structure of the field of ERB research. Future analyses may show a new cluster formed around Shove, if this article's citations continue to increase and it becomes part of the structural network, evidenced by increased ranking by a measure(s) of centrality.

Classification of each article in the co-citation analysis according to one of the four themes – synthesis, motives/values, power, and applicability – showed the following breakdown of the network, overall: 45% of the articles are theoretical (advancing existing and proposing new frameworks or synthesizing literature), 34% pertain to motives and values for ERB, 8% are related to explicit and implicit power dynamics, and 13% are related to real-life applications of theory to promote ERB. The themes did generally map onto the six clusters, such that the two largest Clusters, 0 and 2, were predominantly synthesis, Clusters 4, 5, and 1 were focused on motives/values, power, and applicability, respectively, and Cluster 3 included a roughly equal combination of three themes. This indicates that the structure of the field as a whole is still largely based on the theoretical underpinnings of knowledge (synthesis and understanding the motives and values that lead to behaviour), which aligns with the results from the aforementioned centrality analysis.

2.5.4 Research Fronts - Emerging Trends

Looking at the citation networks within the bibliographic coupling analysis, it seems that cluster 1 (social psychology/values/norms) is the most influential, and perhaps the literature that is most often called to mind

when discussing pro-environmental behaviour (for example, the 10 of the top 20 highest cited articles across the dataset were found in this community. Cluster 1 is the second largest of all the research fronts (in terms of numbers of publications), and the proximity of Clusters 0 and 2 to Cluster 1 on the network map suggest that these clusters draw heavily from the same literature. Cluster 1 tied for the lowest share of papers published in the past six years (note: still not low on an absolute scale, at 65%), however, suggesting both that it is the oldest of the research fronts examined here and, therefore, that interests may be shifting as new research trends emerge. Indeed, though the papers by Stern, and Zelezny et al were amongst the top 5 cited, overall, they do not appear to be core to the network by centrality. The largest nodes in Cluster 1, based on betweenness centrality, were articles that presented path analyses, integrated frameworks, reviews and cross-cultural tests of various behavioural models, such as VBN. The central positioning of these articles in group one suggests that future scholars may be interested in empirical research, testing the robustness of integrated conceptual frameworks rather than the foundational behaviour change theories.

Overall, there appears to be a broad shift in influence from pro-environmental behaviour being a psychological issue of disciplinary definition to (resource) consumption and sustainable lifestyles as a societal issue (clusters 3, 6, 7 and 8). In the bibliographic analysis, the papers with higher centrality tend to be more recent. The highest ranked paper in the network is Tripathi & Singh's (2016) article in Cluster 2, published in the *International Journal of Environmental Technology and Management*, in which the authors use goal frame theory to develop a conceptual model of eco-sensitive consumer behaviours and their predictors. Similarly, the second highest ranked article by van Riper & Kyle (2014) in Cluster 1, published in the *Journal of Environmental Psychology*, implements Latent Class Models to estimate water demand functions for four groups of users who are classified according to their unobservable preferences, in order to account for individual heterogeneity, which means that a common demand function is unlikely to represent the behavior of all users. Indeed, the common theme amongst the top ranked articles, by betweenness centrality, is the problem issue of inconsistent findings in PEB research, due to uncertainty around determinants of actual behaviour versus intention.

2.6 Conclusion and Directions for Future Research

There are two contributions of this research. First, this paper provided an overall appraisal of the environmental behaviour change literature. It systematically characterized the structure of the field by identifying the important/influential theories in ERB research (as demonstrated by citations of peer-reviewed publications). Using the RPYS analysis, it was demonstrated that the year 2000 has been the most important in terms of publications in the field of environmentalism, with several articles from the JSI 2000 Vol. 56 Iss. 3 special issue being the top cited papers published. Second, the extent to which the current literature engages with the themes of the important/influential publications was established. Using two approaches, co-citation analysis and bibliographic coupling, two network analyses were developed, revealing the emerging research fronts in the field.

In the co-citation analysis, six clusters of research were found to provide the structure of the field of ERB. The continued dominance of Stern's paper on the theory of environmental behaviour and Dunlap & Van Liere's paper on the NEP scale from the JSI 2000 special issue was demonstrated by citation counts and four

measures of centrality. Newer work such as Shove's (2010) paper on social practice theory emerged as having the potential to be integrated into the structure of the field, in time.

In the bibliographic coupling, newer papers appear more central to the network, suggesting that discourse in the field has shifted from classical theory to more novel topics. The bibliographic coupling analysis resulted in nine clusters or research fronts (emerging groups). Three of the clusters (0, and 3) focused on the structural roots of the field, namely models, instruments, and frameworks used to measure antecedents of and predict environmental behaviours. Six of the clusters (1, 2, 4, 5, 6, 7, and 8) focused on interventions, applying theories to real-world issues to achieve environmental behavioural outcomes at various scales from individual to national, cross-national, and societal.

In either analysis, the top-ranked papers combined theoretical frameworks and methodologies from multiple different research fronts. For instance, the paper by Bidwell (2013) in Cluster 1 uses structural equation modelling to test the relationship between values/beliefs/norms (i.e., the VBN framework developed by Stern, in the group three intellectual base) and attitudes. The high ranking of Steg & Vlek's integrative review of environmental behaviour change theories suggests that researchers are keen to synthesize the theoretical knowledge that exists in the field when applying theory to empirical research.

This paper demonstrated that the overall structure of the ERB field is entrenched in theory, and that the majority of researchers publishing in the field are continuing to discuss the models, instruments, and theoretical frameworks. This paper also demonstrated that the emerging research fronts are highly applied, signally an effort to utilize knowledge to address climate change through evidence-based intervention design and implementation. Future research could build upon this work by applying other types of bibliometric analyses to both the broader dataset and the co-citation and bibliographic networks. For example, a co-authorship network would provide information about the extent to which the ERB field is interdisciplinary. A weighted keyword coupling network extends the results of a keyword frequency analysis, enriching the understanding of the language used in a field of research, the connectedness between terms and the labels used to assign meaning.

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Chapter 3 – A multi-level model of local distribution companies' achievement of peak and cumulative electricity conservation in Ontario

3.1 Introduction

Energy efficiency plays a prominent role in many national energy policy strategies, from consumers' willingness-to-pay for ENERGY STAR labels (Ward et al., 2011), the effectiveness of utilities' programs to promote energy efficiency (Friedrich, Eldridge, York, Witte, & Kushler, 2009; Gillingham et al., 2006), to the importance of user behaviour versus efficient technology in achieving reduced consumer consumption (Gram-Hanssen, 2013). Indeed, it is estimated that global government and utility spending on energy efficiency was US$25.6 billion in 2017, and is expected to grow to US$56.1 billion in 2026 (Navigant Research, 2018). This level of spending is warranted because there are many benefits of energy efficiency (defined as using less to achieve the same level of service), for individuals and society, more broadly. In 2014, the Partnership for Energy Efficiency Collaboration (IPEEC) established a task group to collate and report detailed technical work on energy efficiency finance, as one of six workstreams under the G20 Energy Efficiency Action Plan. In 2016, the Energy Efficiency Finance Task Group (EEFTG) established three compelling reasons for G20 countries to prioritize and up-scale energy efficiency investments:

1. Economic: Energy efficiency lowers energy bills at all scales and has the potential to create levels of employment to the same degree as infrastructure programming. It also creates supply without the need for new generation, increasing energy security.

2. Climate: Energy efficiency can deliver approx. 50% of the GHG emissions reductions needed, pre-2035, to keep the planet to a 2-degree Celsius increase. This level of energy efficiency is estimated to cut the cost of climate action needed by $ 2.8 trillion.

3. Development: Energy efficiency is critical to achieving the United Nations' 7th Sustainable Development Goal (SGD) to "ensure access to affordable, reliable, sustainable, and modern energy for all". Currently, there is an estimated $430 billion USD shortfall in energy efficiency investments if this goal is to be met (essentially, the global rate of energy efficiency improvements needs to double) (IPEEC, 2016).

While the enormous and increasing amounts of taxpayer dollars being spent on energy efficiency around the world are promising, the varying degrees of performance outcomes resulting from these efforts are cause for concern. Examinations of energy efficiency policies in the United States have shown only modest impact on national GHG emissions reductions, and that defining energy as a demand-side resource limits the extent to which energy efficiency can be achieved (Gillingham et al., 2006; Thoyre, 2015). Globally, evaluations of household energy efficiency programmes have reported average energy savings from 1% in New Zealand to 66% in Japan (Wade & Eyre, 2015). In

addition, spending public funds to reduce negative externalities (e.g., rewarding energy conservation and pollution abatement) instead of correcting the internalization of external costs (e.g., pricing and taxing GHG emissions) creates asymmetric incentives, leading to heterogeneous results. For example, consumption reduction in a residential electricity rebate program in California ranged from zero (coastal homes) to 5% (inland homes), with an overall program cost of 17.5 cents per kWh reduction and US$390 per ton of CO_2 reduction (Ito, 2013).

Discussion about expenditures of public funds, particularly the effectiveness of energy efficiency public policies, can be found in both academic and non-academic literature (e.g., Charlier, 2015; Darnton, 2008; Dixon, 2014; Gillingham, Harding, & Rapson, 2012). The on-going debate regarding the effectiveness of mergers and acquisitions (M&As) in the power sector (Frank J. Cronin, 2007; Kushner & Ogwang, 2014; Kwoka & Pollitt, 2010) also demonstrates academic interest in the determinants of utility costs for provision of energy services. Cronin (2007) and Kushner & Ogwang (2014) studied the Ontario context, examining the determinants of utility costs and exploring whether larger utilities (including mergers and amalgamations) have resulted in cost savings.

This paper contributes to the discourse by investigating the effectiveness of energy efficiency expenditures, administered at the provincial level and offered as incentive programs through regional electricity distribution utilities. Specifically, two useful inquiries at this scale (recognizing, of course, that other levels within the energy system also require further research) are: *how can the variability in achievement of energy efficiency targets by distribution utilities be explained*; and *how can the variability in the rate of change towards energy efficiency targets by distribution utilities be explained*? The province of Ontario will be investigated as a case study to address these questions.

The province of Ontario's energy policy is to "invest in conservation first, before new generation, where cost-effective" (MOE, 2013, Minister's message). Under the Conservation First Framework (CFF), local distribution companies (LDCs) are provided with long-term funding for CDM programs; C$1.8 billion was budgeted for 2011-2014 implementation (OPA, 2014). In 2015, Ontario's Auditor General highlighted this spending as ineffective for many reasons: 36% of the spending on conservation initiatives was not evaluated by an independent third-party for cost-effectiveness; from 2006-2014, the province's electricity consumption decreased by 8% while the overall price of electricity to consumers increased from 2004-2014; over 90% of the utilities did not achieve their peak demand reduction targets; when asked in an online survey (conducted by the Ministry of Energy) in 2013 how well their community was doing at reducing electricity demand, 40% of Ontarians responded that they could not see any evidence of conservation efforts (Office of the Auditor General of Ontario, 2015).

This paper aims to explain the achievement of CDM targets by LDCs in Ontario, as per the Conservation First Framework. Contributing to the debates regarding the cost-effectiveness of conservation spending in Ontario, or the need for conservation initiatives in an electricity-surplus context is out of scope for this study, which is focused on the utility-level CDM performance within the 2011 to 2014 period. This paper briefly reviews literature that attempts to explain the

performance of electricity distribution utilities (CDM and other conventional metrics of performance). It investigates a case study of CDM as part of electricity power planning in Ontario to determine if certain characteristics of utilities have influenced conservation outcomes, and how.

The structure of this paper is as follows. After this introductory section, the literature on the performance evaluation of distribution utilities is discussed in Section 2. Section 3 presents Ontario's conservation landscape. Sections 4 and 5 discuss the methodology for the data analysis and include a discussion on the input/output selection criterion. Section 6 analyses explanatory variables based on the hierarchical linear model proposed in the paper. A concluding Section 7 follows the analysis of results.

3.2 Literature review

3.2.1 Benchmarking performance - Conventional inputs, outputs, and methods

The traditional definition of economic efficiency (i.e. cost effectiveness of production at a given level of technology) is prominent in the discourse regarding energy efficiency policy and programs (Aguero & Khodaei, 2015; Cronin, 2007; Farsi & Filippini, 2004; Friedrich, Eldridge, York, Witte, & Kushler, 2009; Kushner & Ogwang, 2014; von Hirschhausen, Cullmann, & Kappeler, 2006; Yu, Jamasb, & Pollitt, 2009). The literature is less clear on an agreed upon definition of efficiency, in general terms, for electricity distribution utilities, in particular. Efficiency is generally defined as a comparison between the use of inputs and the corresponding production of outputs (Cui, Kuang, Wu, & Li, 2014), but there are numerous factors that can be chosen for each, for example: labour, expenses, capital and stock as inputs, and CO_2 emissions, distribution system peak load and retail sales as outputs (Cui et al., 2014; Pahwa, Feng, & Lubkeman, 2002). Researchers have criticized the use of market indicators (e.g. profitability and rates of return) to measure and compare the performance of electric distribution utilities because they operate in a non-competitive market; their planning is seen as primarily responsive to regulation (Abbott, 2005; Didden & D'Haeseleer, 2003). These researchers suggest that productivity can be measured as an index number, constructed by changes in various levels of production inputs and outputs (Kendrick, 1961, Kendrick & Grossman, 1980, cited in Abbott, 2005). Recognizing the systems view of electricity and the flow of services it provides, Irastorza's (2003) emphasis on balancing the "interests of consumers and those of investors by ensuring that utilities provide adequate service at reasonable prices, while remaining financially viable and receiving clear investment incentives" (p. 31) is an appropriate complement to the traditional definition of economic efficiency.

Benchmarking – setting customer prices or outputs based on a measure of 'efficient' vs. actual costs – the performance of utilities has become a widely applied international practice in the regulation of electricity, in order to inform policy decisions around threshold efficiency levels, electricity rates, incentive levels, and ensure adequate demand to meet supply, more broadly (e.g. Irastorza, 2003; Jamasb & Pollitt, 2001; Thakur, Deshmukh, & Kaushik, 2006). Econometric models – those that combine explicit economic theories with statistical models (Reiss & Wolak, 2007) – have been used to benchmark distribution utility performance with respect to cost-efficiency (Farsi & Filippini,

2004; Santos, Amado, & Rosado, 2011; von Hirschhausen, Cullmann, & Kappeler, 2006) and reliability (Fenrick & Getachew, 2012). Econometric models have also been used to study the impact of energy efficiency policies using customer consumption data (Horowitz & Bertoldi, 2015).

Just as there are no universally agreed upon indicators of production efficiency for electricity distribution utilities, there is no consensus in the literature regarding the choice of inputs and outputs for benchmarking their performance. In econometric evaluation, a range of distribution and supply functions have been used (Cui et al., 2014; Fenrick & Getachew, 2012; Jamasb & Pollitt, 2001). Variables for analysis have been categorized as assets/capital, expenses/costs, and sales/capacity (Cronin, 1999; 2007; Pahwa, Feng, & Lubkeman, 2002). Likewise, a range of independent variables (IVs) and dependent variables (DVs) can be seen in statistical studies of electric utilities (Farsi & Filippini, 2004; Kushner & Ogwang, 2014). Clustering and pattern recognition of multivariate time series models has recently been presented as a new method of statistical analysis to support decision-making in the electricity sector (Ferreira, Fontes, Cavalcante, & Marambio, 2015). Researchers and policy-makers alike make judgement calls in determining 'fair' rates of return for utilities, along with 'reasonable' prices for consumers (Sueyoshi, Goto, & Ueno, 2010; Yu, Jamasb, & Pollitt, 2009), which can be translated into minimum thresholds of efficiency for electric utilities. These thresholds are subsequently used as benchmarks, which are then jurisdictional or contextual, to some degree.

3.2.2 Conservation performance - Can benchmarking output explain it?

Energy efficiency is positioned by many government institutions as the most cost-effective energy resource option within a utility's portfolio (Friedrich et al., 2009). This casts distribution utilities in a 'front line' role as promoters of energy conservation programs to their customers. Charnes, Cooper & Rhodes (1978) proposed the development of measures to evaluate the 'decision making efficiency' of such decision-making units (DMUs) in the context of standardized or regulated outputs. From a policy perspective, the question then becomes how to properly support and incent distributors to assist their customers in achieving the level of conservation desired by the governing institution(s). This leads to the natural follow up question regarding whether some distributors are better suited than others to secure conservation behaviour from their customers, in parallel to conventional benchmarking on economic efficiencies.

This paper posits that achievement of conservation performance targets (i.e., metrics based on desired outputs of conservation programs and government spending on energy efficiency) may be explained by the output(s) used for the conventional benchmarking of distribution utilities. In the evaluation of these public programs, there is interest in the 'relative efficiency' of DMUs (Charnes, Cooper, & Rhodes, 1978; von Hirschhausen et al., 2006), while recognizing that "some DMU's are more like members of one subset and less like members of other subsets" (Charnes et al., 1978, p. 430). This heterogeneity may impact the utilization of inputs and the ability for certain utilities to produce the desired outputs. Findings from this analysis may produce insights that governments can use to improve the effectiveness of energy efficiency and conservation programs. This paper presents Ontario's Conservation First Framework (CFF) as a case study to explore this idea.

3.3 The Ontario Energy Conservation Landscape

Ontario is Canada's second largest province in area, with the nation's largest population, most of which live in urban areas concentrated in Southern Ontario. There are nine climate zones (variability in daily temperatures and light intensity) in Southern Ontario, with average temperatures varying greatly and frost-free days ranging from 90 – 190 (OMAFRA, 2016). Natural Resources Canada classifies the province as having two Energy Star climate zones, northern Ontario as Zone 3 (greater than or equal to 6000 Heating Degree Days (HDD), as per the Canadian Model National Building Code) and central/southern Ontario as Zone 2 (greater than or equal to 3500, but less than 6000 HDD) (NRCan, 2018). Ontario's electricity sector is a mix of private- and publicly-held generators, transmitters, distributors, retailers, licensed by the provincial government (OEB, 2018). In November 2015, the previously province-owned Hydro One Networks Incorporated (HONI), which operates approximately 97% of the high-voltage transmission grid, became a publicly-traded company on the Toronto Stock Exchange (TSX) (HydroOne, 2018). A crown corporation, the Independent Electricity System Operator (IESO) operates the province's electricity market, directs the operations of the bulk electrical system, and administers the conservation and demand management (CDM) program. Ontario's local distribution companies (LDCs) are a mix of provincially-, municipally-, privately-, and publicly-owned and operated entities that supply electricity to approximately 95% of Ontarians (the remaining 5% purchase electricity from private electricity retailers under contract) (OEB, 2018).

As the evolution of Ontario's electric power system has been analyzed and presented by others (e.g., Rosenbloom & Meadowcroft, 2014), this paper begins with the provincial government's 2010 directive to meet future electricity demand through natural gas, renewable energy sources and conservation. Energy conservation has been identified as a critical and strategic component of Ontario's sustainable energy future, as conservation and demand management optimizes existing infrastructure, reducing the need for new builds and the associated monetary and environmental burdens (MOE, 2013). Electricity conservation is also a core component in Ontario's future electricity plans given the significant economic and environmental benefits; it is estimated that for every $1 invested in energy efficiency, $2 in spending on electricity infrastructure and climate costs (present day) are avoided (IESO, 2014).

On March 31, 2010, the Minister of Energy and Infrastructure issued a directive (the "Directive") to the Ontario Energy Board (OEB) regarding CDM Targets to be met by the province's LDCs. The Directive gave the OEB authority to, without hearing, amend the LDCs' electricity distribution licenses to include the requirement to achieve reductions in electricity consumption and reductions in peak electricity demand by the amounts specified by the OEB. These reductions were to be achieved through the delivery of CDM programs, over a four-year period beginning January 1, 2011. With respect to allocating the total provincial target of provincial peak demand (MW) and total reduced electricity consumption over the four-year period (GWh) to the individual LDCs, the OEB was also directed to consult the Ontario Power Authority (OPA, now part of IESO) on the methodology for allocating the distributor-specific CDM Targets. After receiving written comments from 27 LDCs

(approx. 38%) on its draft advice document, the OPA recommended the following peak demand savings target and energy savings target allocation methodology, using 2008 and 2009 energy consumption data[13]:

Individual LDC Peak Demand Savings Target (MW) = Dem%*LDC Provincial Aggregate Peak Demand Savings Target of 1,330 MW

Where:

Dem% = (Dem%Yr1 + Dem%Yr2) ÷ 2

Dem%Yr1 = Sum of LDC demand at top 10 system peak hours in Year1 ÷ Sum of demand of all LDCs that have CDM Targets at top 10 system peak hours in Year1

Dem%Yr2 = Sum of LDC demand at top 10 system peak hours in Year2 ÷ Sum of demand of all LDCs that have CDM Targets at top 10 system peak hours in Year2

Yr1 = 2008

Yr2 = 2009

Individual LDC Energy Savings Target (MWh) = RE% * RE + NRE% * NRE

Where:

RE% = LDC Annual Energy Consumption for all Residential Customers ÷ Sum of Annual Energy Consumption for Residential Customers for all LDCs that have CDM Targets (using an average of 2008 and 2009 data)

RE = Total Projected Residential Sector Contribution to LDC Provincial Aggregate Energy Savings = 1150 GWh

NRE% = LDC Annual Energy Consumption for all Non-Residential Customers ÷ Sum of Annual Energy Consumption for Non-Residential Customers for all LDCs that have CDM Targets

NRE = Total Projected Non-Residential Sector Contribution to LDC Provincial Aggregate Energy Savings Target = 4850 GWh

The OEB issued the final target allocation on March 14, 2011 via Directive and Order EB-2010-0215 / EB-2010-0216 (LDC targets have been included in Appendix A).

There are 72 LDCs in Ontario[14], ranging in size with respect to service territory/geography, number of customers (in all three categories – residential, commercial, and industrial), and infrastructure

[13] Summarized from the OPA's Advice to the Ontario Energy Board: CDM Target Allocation for Ontario LDCs

under management. Analysis of the OEB electricity distributor scorecards indicates that only 7% of LDCs met both of their CDM targets (peak and cumulative savings) by the end of 2014, 1% met only their peak savings target, and 50% met their cumulative savings target, only, and 42% met neither target. In keeping with the previous discussion of benchmarking and efficient use of taxpayer dollars in conservation programming, this paper presents achievement of the CDM targets as 'success', with no assumptions made about the appropriateness of the targets. This research aims to explain, empirically, the CDM performance by Ontario's LDCs in the 2011-2014 CFF period, and whether the LDCs that achieved the targets share certain characteristics vis-à-vis those that did not. By doing so, the authors seek to contribute original critical analysis to discourse on CDM policies and tools at the provincial-level, and more generally.

3.4 Hierarchical Linear Modelling Fundamentals

3.4.1 Hierarchical linear modelling - A primer

Hierarchical linear modeling (HLM) is a type of regression analysis that allows for the simultaneous estimation of variation across two or more analytical levels (e.g., students and schools), and is, thus, ideal for the analysis of data with dependent observations (Raudenbush & Bryk, 2002). The lowest level of clustering in the model is referred to as Level-1. This is the individual level, or the level where repeated measures[15] are taken for an individual (or organization). The model for Level-1 is structured similarly to that of an Ordinary Least Squares (OLS) regression, where an outcome (dependent) variable is predicted as a function of a linear combination of one or more Level-1 variables, plus an intercept, as follows:

$$Y_{ij} = \beta_{0j} + \beta_{1j} X_1 + \ldots + \beta_{kj} X_k + r_{ij}$$

Where β_{0j} = the intercept of group j,

β_{1j} = the slope of variable X_1 of group j, and

r_{ij} = the residual for individual i within group j.

At Level-2 (and all subsequent), the Level-1 (or lower level) slope(s) and intercept become dependent variables being predicted from Level-2 (or higher level) variables:

$$\beta_{0j} = \gamma_{00} + \gamma_{01} W_1 + \ldots + \gamma_{0k} W_k + u_{0j}$$

$$\beta_{1j} = \gamma_{10} + \gamma_{11} W_1 + \ldots + \gamma_{1k} W_k + u_{1j}$$

[14] Due to mergers and acquisitions, the number of LDCs in the province changed over the 2011-2014 period (from 77 to 72; there were 77 LDCs in 2012). The statistical analysis reflects the LDCs in 2014.

[15] Data gathered on individuals or organizations for the purpose of measuring and monitoring performance and/or growth (i.e., multiple observations on the same parameters are gathered over time) are considered 'repeated measures' data and are hierarchical (Raudenbush & Bryk, 2002; Osborne & Neupert, 2013).

and so on, where γ_{00} and γ_{10} are intercepts, and γ_{01} and γ_{11} represent slopes predicting $\beta 0_j$ and β_{1j}, respectively, from variable W_1 (J. Osborne & Neupert, 2013).

Through an iterative model development process, the effects of Level-1 variables on the outcome, and the effects of Level-2 variables on the outcome, etc. (the relationships within and between hierarchical levels), are simultaneously, effectively, and efficiently modelled (Woltman, 2012). In addition, since slopes (rates of change) are being predicted, as well as intercepts (means), cross-level interactions can also be modelled, in order to explain interaction between Level-1 and Level-2 variables.

3.4.2 Hierarchical data structure of longitudinal data

Hierarchies within longitudinal or repeated measures data are less obvious than other nested structures such as people within hierarchical social and organizational structures such as families, workplaces, and communities (J. W. Osborne, 2000). Observations over time for an individual tend to share certain characteristics attributed to the individual, and will be more similar or homogenous than observations randomly sampled from a larger population. Repeated measure data have an individual or organization as the structural unit of the higher-level, and the longitudinal time points as the lower-level, nested within the individual or organization.

3.4.3 Modelling longitudinal data - Advantages of HLM

Analyzing cumulative hierarchical data (e.g., percentage achievement of a target such as a fundraising goal) presents intractable challenges for most statistical techniques, due to the violation of the primary assumption, the requirement for independence of observations. With cumulative data, only positive change can be studied, since values can never be lower than the previous, thus restricting the variance between observations. Ordinary least squares (OLS) regression, Analysis of Variance (ANOVA), and most other parametric statistical procedures conducted on hierarchical data will produce standard errors that are too small, leading to a higher probability of rejection of a null hypothesis (i.e., Type I error) (J. Osborne & Neupert, 2013). Examining longitudinal data or growth curves across individuals, simultaneously, provides the ability to analyze what factors or variables predict growth curve components such as the starting or end point and rate of change (Biesanz, Deeb-Sossa, Papadakis, Bollen, & Curran, 2004).

Researchers in psychology have demonstrated the effectiveness and advantages of applying HLM in clinical (Bickman, Kelley, Breda, Regina de Andrade, & Riemer, 2011), organizational (Fisher, 2014), and educational (Osborne, 2000) settings. For example, an empirical test of the three approaches to analyzing hierarchical data (disaggregation, aggregation, and HLM) demonstrated that only HLM accurately modelled the relationships between the outcome and predictor variables (Osborne, 2000). The disaggregated analysis, where school-level data from the National Education Longitudinal Survey were modelled at the student-level, significantly overestimated the effect of socio-economic status (SES) and significantly and substantially underestimated the effects of the school-level effects. The aggregated analysis, where student-level data were aggregated to the school-level, overestimated the multiple correlation by more than 100%, and significantly

overestimated and underestimated the slopes of several other variables. The HLM model demonstrated goodness of fit and revealed expected relationships between the student- and school-levels.

Using HLM on non-hierarchical data with no dependence or other issues would yield virtually identical results to OLS regression, so there is no disadvantage of using this method (Osborne & Neupert, 2013).

3.4.4 Applying HLM to the analysis of LDCs

HLM is an appropriate tool to analyze the CDM performance of Ontario's LDCs, because the performance of any given LDC over the course of the Conservation First Framework time period is best represented by a growth curve. This is the case for CDM or any indicators of cumulative performance over time, since values for each LDC can never be lower than the prior year. Variance in the growth curve model is restricted at Level-1, time. HLM has many advantages when analyzing this type of nested data. It requires fewer assumptions to be met compared to other statistical methods (Raudenbush & Bryk, 2002), accommodating non-independence of observations such as cumulative data. In addition, using HLM allows for simultaneous modelling of both the intercept (the achievement of the CDM target in 2014) and the slope (the rate of change toward the target) at Level-1 for each LDC, as well as the intercept and slope across all LDCs at Level-2.

3.4.5 Limitations of HLM

One general limitation of HLM that is relevant for this study is the requirement for relatively large sample sizes, particularly at the higher levels of the model. Hofmann (1997) explains this requirement using the findings of several simulation-based investigations of the statistical power of HLM models. With regard to estimating Level-2 effects, the number of Level-2 units (i.e., LDCs) has more effect on the statistical power of the model than the number of Level-1 units or observations (i.e., time points per LDC). For estimating Level-1 effects, statistical power is more dependent on the total sample size. Overall, having more Level-2 units reduces the number of Level-1 units or observations required and conversely, having fewer Level-2 units increases the number of Level-1 units needed to obtain sufficient power (Hofmann, 1997). In this study, statistical power was sufficient for determining whether the variability in achievement of the Cumulative Target and the variability in rate of change towards the Cumulative Target by the LDCs was statistically significant.

3.5 Methodology

3.5.1 Data

The Ontario Energy Board (OEB) regulates the province's electricity and natural gas industries, setting the rates that utilities charge for the delivery of electricity to its consumers through a formal application and approval process. The OEB monitors the financial and operational performance of the utilities, and publishes data collected from the utilities in two formats: 1) The annual Yearbook of Electricity Distributors (Yearbook), which contains detailed information on balance sheet and income statement metrics, traditional performance metrics (e.g., service quality indicators), the number of customers (by customer class), total service area (rural or urban), and total kWh

delivered; 2) Utility scorecards, with data for 20 specific measures related to four key areas of performance: customer focus, operational effectiveness, public policy and responsiveness, and financial performance. These documents are available for download on the OEB's website, encouraging the LDCs to operate effectively and seek continuous improvement, and supporting open and transparent dialogue with the public about the overall performance of the energy distribution system (OEB, 2018).

Following Kushner & Ogwang (2014), the OEB's Yearbook will be used as the data set for this analysis. Additionally, the percentage of Peak and Cumulative target achieved will be drawn from OEB's annual Scorecards for the 4-year period from 2011 to 2014. The yearbook data are presented visually in Figures 13 to 15 and Table 5, below.

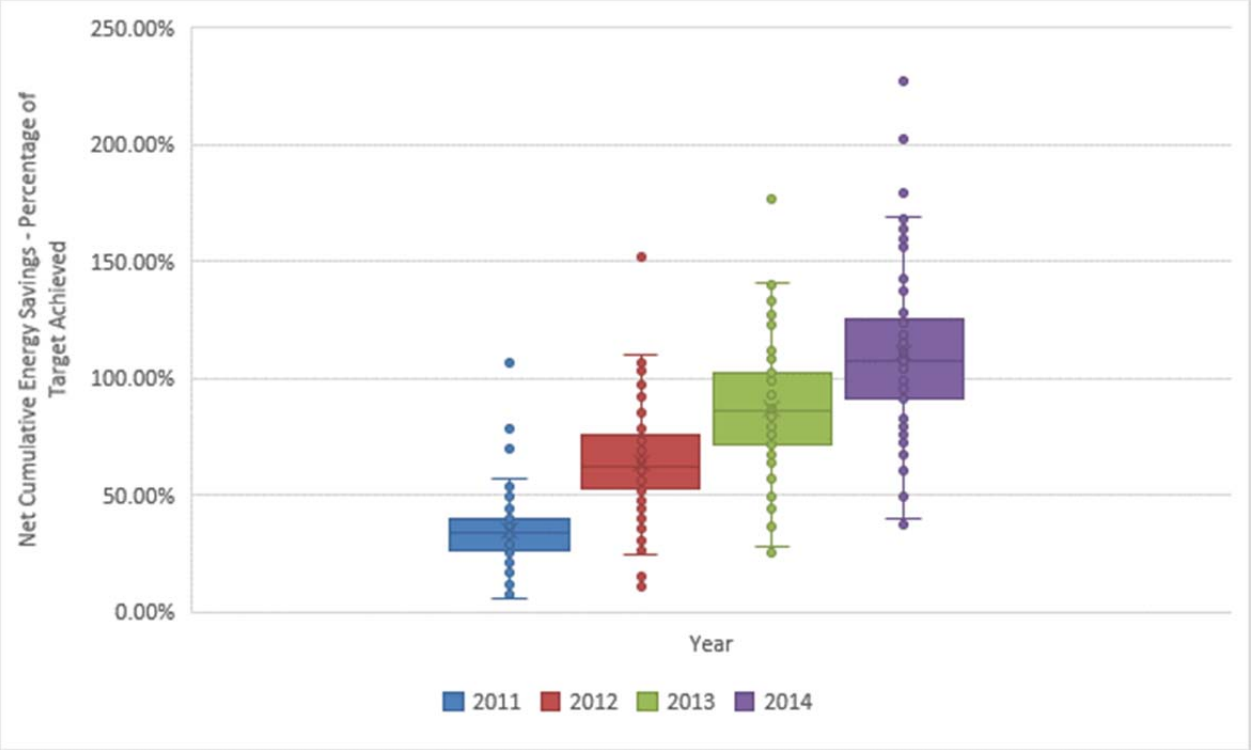

Figure 13: LDC Achievement of Net Cumulative Energy Savings Target over 2011-2014 Conservation First Framework

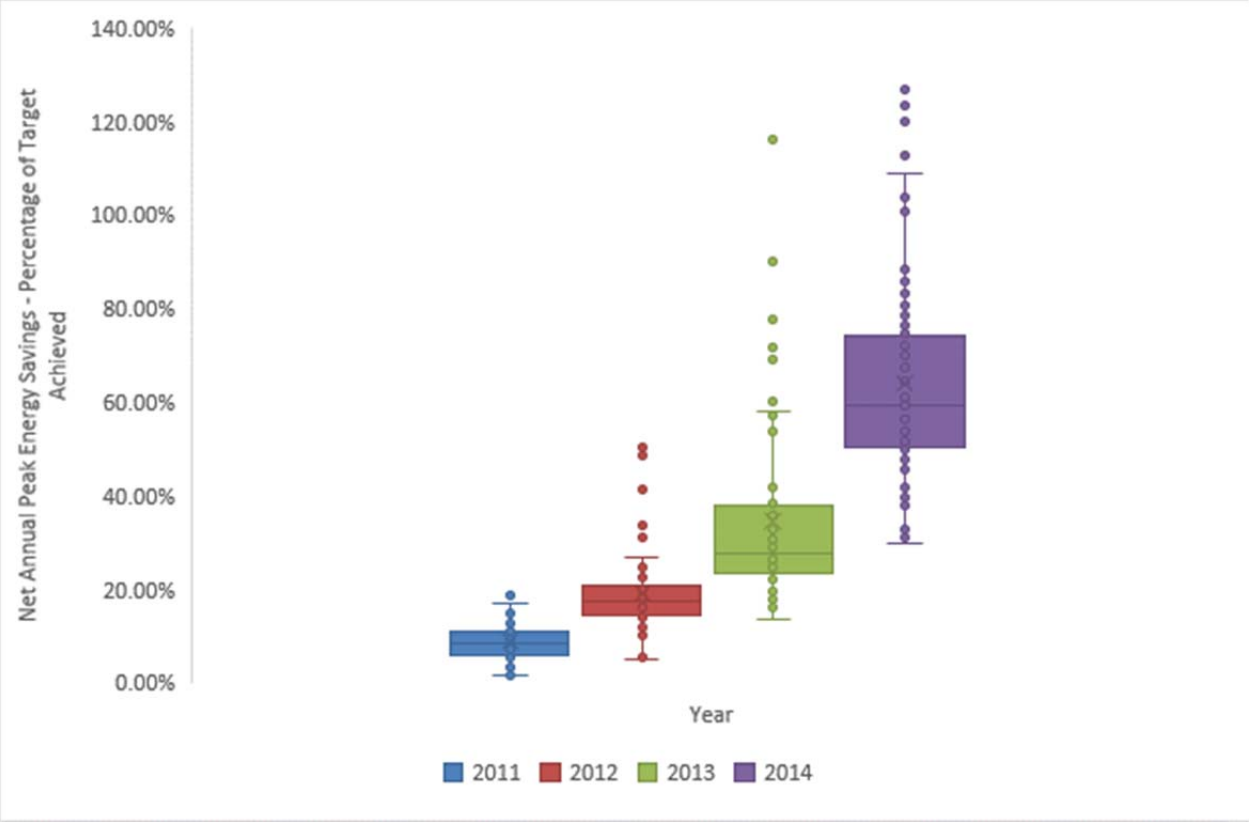

Figure 14: LDC Achievement of Net Annual Peak Energy Savings Target over 2011-2014 Conservation First Framework

As illustrated in Figures 13 and 14, there is a visible variability among LDCs with respect to achievement of their targets in 2014 and the rate of progress towards their targets over the framework period. Only 8% of LDCs achieved or exceeded their Net Annual Peak Energy Savings target by 2014, and only 56% of LDCs achieved or exceeded their Net Cumulative Energy Savings target by 2014. The movement of the LDCs as a group towards their respective targets is outlined and visualized in Table 5 and Figure 15, respectively.

Table 5: LDCs' achievement of CDM targets over the 2011-2014 CFF period

	2011	2012	2013	2014
LDCs that have reached their Net Annual Peak Energy Savings target (# / %)	0 (0%)	1 (1%)	1 (1%)	6 (8%)
LDCs that have reached their Net Cumulative Energy Savings target (# / %)	1 (1%)	6 (8%)	19 (26%)	40 (56%)

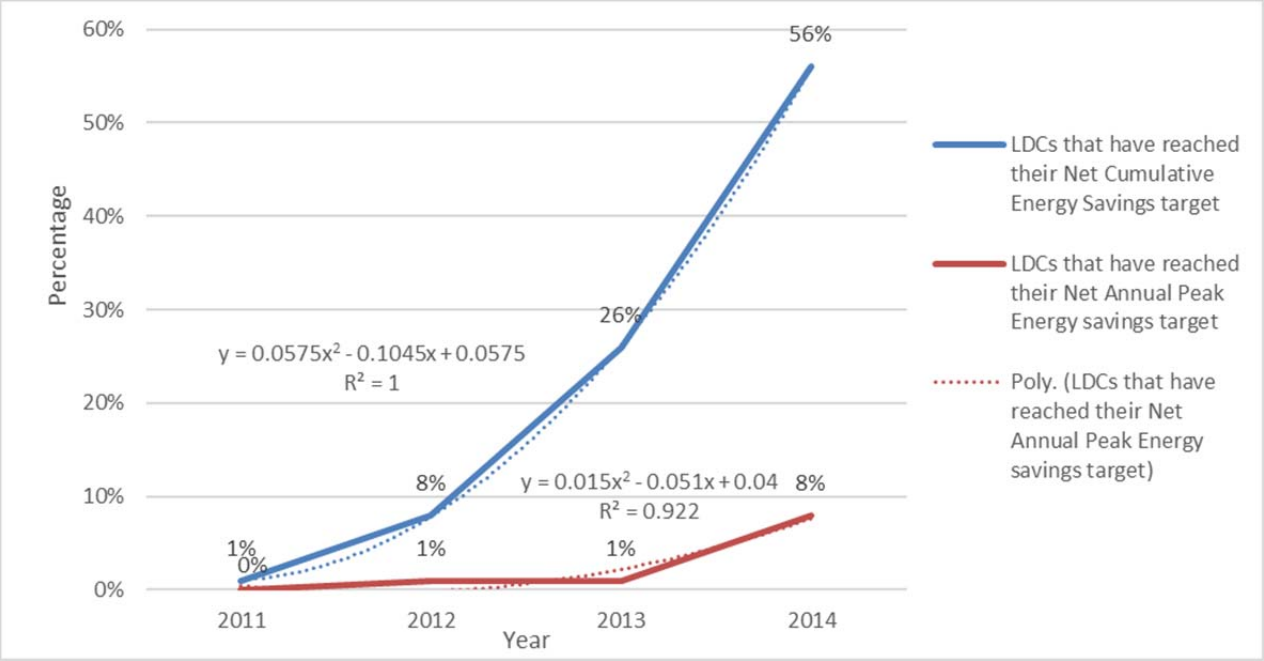

Figure 15: Visualization of LDCs' achievement of CDM targets over the 2011-2014 CFF period

3.6 Model specifications

A 2-level hierarchical, longitudinal, slopes-as-outcomes model with random coefficients was used to explain the achievement of the CDM targets by individual LDCs:

Peak Target: Net Annual Peak Energy Savings, expressed as a percentage of each LDC's unique target, set by the Ontario Energy Board and amended to each LDC's license, pursuant to sections 27.1 and 27.2 of the Ontario Energy Board Act, 1998, under Directive EB-2010-0215/EB-2010-0216. The LDC CDM Targets were published in Appendix C of the Directive on March 14, 2011, and have been reproduced in Appendix D of this paper.

Cumulative Target: Net Cumulative Energy Savings, expressed as a percentage of each LDC's unique target, set by the Ontario Energy Board and amended to each LDC's license, pursuant to sections 27.1 and 27.2 of the Ontario Energy Board Act, 1998, under Directive EB-2010-0215/EB-2010-0216. The LDC CDM Targets were published in Appendix A of the Directive on March 14, 2011, and have been reproduced in Appendix D of this paper.

A two-level HLM was estimated for the Cumulative Targets[16]. The 2-level HLM can be conceptualized as the process of first assessing individual-level change (repeated measures from 2011-2014 for each LDC), then predicting individual-level differences in change (between LDCs), if

[16] The 2011-2014 OEB Scorecards published two CDM scores, the Net Annual Peak Demand (Peak) Savings (% of Peak Target achieved) and Net Annual Cumulative Savings (% of Cumulative Target achieved). By calculating the intra-class correlation coefficient (ICC), which gives an indication of how much variance there is between the Level-2 units, it was determined that insufficient (0.09%) of the variance in Peak achievement could be explained at the LDC-level, Therefore, an HLM was not generated for this dependent variable. It is noteworthy that in the 2015-2020 Conservation First Framework, there are no Peak Targets for the LDCs.

they exist. At Level-2, the question is whether characteristics of LDCs help predict why some have higher CDM target achievement than others.

As this is the first study, to the authors' knowledge, that has investigated the determinants of electric distribution utilities' achievement of CDM targets, there are few examples from which to draw empirical knowledge on which to base the selection of independent variables for the proposed model. As such, this study draws from the econometrics literature, taking factors that have been shown to impact distribution utilities' operational efficiency as potential determinants of conservation performance. The following independent variables were tested at the LDC-level (Level-2) of the HLM:

Customer density: The number of customers per square kilometre of LDC service territory. As with other public services, the expectation is that higher density lowers the unit cost of service delivery (e.g., Kushner & Ogwang, 2014). In this case study, higher density is expected to predict higher achievement of conservation targets.

Total number of customers and **Customer mix:** The ratio of residential customers to all other customers. The Yearbook includes residential customers, general service (non-residential) users at less than and greater than 50 kW capacity per month, large-user customers at greater than 5000 kW capacity per month, and sub-transmission users. LDCs with a higher ratio of residential to larger users are expected to have higher unit costs (suggesting a negative relationship, as per Kushner & Ogwang, 2014), but also a higher allocation of funds from the CFF, given the load- and population-based methodology for budget allocation OPA, 2014), therefore a positive relationship between customer mix and CDM target achievement is expected.

Financial indicators (Debt-to equity, Total cost per customer and per kW): Some debt is required to finance capital projects (e.g., Jamasb & Pollitt, 2001; Kushner & Ogwang, 2014). Similar to operational performance, it is expected that there is an optimal ratio to achieve desired CDM performance.

Census area: In Canada, municipalities are classified as: Census Metropolitan Area (CMA) – total population of at least 100,000, but greater than 50,000; Census Agglomeration Area (CA) - population of at least 50,000, but less than 100,000; and Rural and Small Town (RST) – population of at least 10,000, but less than 50,000. This classification, along with the Yearbook data (number of residential customers) and Statistic Canada's 2011 census data, was used to classify each LDC as servicing a CMA, CA, or RST[17] , as opposed to simply 'urban' or 'rural'. It is posited that LDCs servicing Rural and Small Towns will be less likely to achieve their CDM targets.

The HLM-7 (version 7.03) software was used to estimate the model, by using full maximum likelihood (MLF) estimation. MLF estimation is required for developing the multilevel through iterative estimation of the intercepts and slopes, and to determine model fit through model

[17] In Ontario, 10% of homes in were singly occupied, and the remaining are occupied by an average of 3 people.

comparison. When estimating the final model, restricted maximum likelihood (MLR) was used because of the relatively small number of Level-2 units (n=72 LDCs); when n is small, MLF is less sensitive[18] than MLR in detecting variance estimates. Table 6 presents the descriptive statistics for the Level-2 variables that were assessed.

Table 6: Descriptive statistics of key variables

Variable Name	**2011**	**2012**	**2013**	**2014**
	Mean (SD) [Min] <Max>	Mean (SD) [Min] <Max>	Mean (SD) [Min] <Max>	Mean (SD) [Min] <Max>
Net Annual Peak Demand Savings (% of Target achieved)	8.93% (4.71%) [1.33%] <32.20%>	19.31% (8.68%) [5.00%] <57.30%>	33.16% (16.41%) [12.30%] <90.00%>	63.09% (19.99%) [29.80%] <123.34%>
Net Cumulative Energy Savings (% of Target achieved)	34.77% (16.70%) [6.02%] <106.86%>	63.60% (23.86%) [11.10%] <152.00%>	86.14% (26.38%) [25.40%] <176.60%>	109.95% (33.82%) [37.16%] <226.87%>
Peak Target (MW)	18.69 (44.57) [0.19] <286.77>	18.69 (44.57) [0.19] <286.77>	18.69 (44.57) [0.19] <286.77>	18.69 (44.57) [0.19] <286.77>
Cumulative Target (GWh)	84.40 (212.07) [1.04] <1,303.99>	84.40 (212.07) [1.04] <1,303.99>	84.40 (212.07) [1.04] <1,303.99>	84.40 (212.07) [1.04] <1,303.99>
Total number of customers	66,447 (169,155) [1,208] <1,210,695>	67,038 (169,741) [1,216] <1,221,036>	67,773 (170,795) [1,220] <1,220,101>	69,290 (172,526) [1,221] <1,219,292>
Customer Density (# of Customers per sq. km of Service Area)	297.09 (233.84) [0.82] <1,125.91>	302.79 (234.46) [0.82] <1,140.73>	305.38 (236.60) [0.82] <1,165.99>	310.07 (240.80) [0.82] <1,181.35>

[18] When the number of Level-2 units is small, MLR estimation produces variance estimates that are smaller than those produced by MLR by a factor of (n-N)/n, where N is the total number of elements in the fixed effects vector (Raudenbush & Bryk, 2002).

Variable Name	2011	2012	2013	2014
Debt-equity ratio	1.02 (0.60) [0.12] <3.79>	1.09 (0.79) [0.10] <5.13>	0.98 (0.50) [0.08] <3.31>	1.01 (0.53) [0.05] <3.26>
Total cost per customer ($)	1,959.69 (392.77) [903.31] <3,329.16>	2,055.72 (417.42) [896.05] <3,396.03>	2271.62 (498.90) [1,017.50] <3,656.56>	2390.45 (486.23) [1,117.19] <3,675.96>
Total cost per kW ($)	0.08 (0.01) [0.05] <0.09>	0.09 (0.01) [0.06] <0.11>	0.10 (0.01) [0.06] <0.12>	0.10 (0.01) [0.06] <0.11>
Customer mix (Residential / Other customers)	8.48 (2.30) [4.7] <15.70>	8.5 (2.30) [4.59] <15.74>	11.54 (25.55) [4.77] <227.53[1]>	12.22 (30.66) [4.82] <269.93[1]>

[1]In 2013 and 2014, Algoma Power Inc. reported having 0 customers in the General Service category (< 50 kW), down from 922 in 2012.

Prior to inputting independent variables into the model, including time and quadratic time (the latter because the plot of Peak target achievement from 2011 to 2014 displayed a non-linear growth pattern), fully unconditional models for each dependent variable were estimated to determine whether sufficient between- and within-subjects variance in Peak and Cumulative Target Achievement existed. The intra-class correlation coefficient (ICC) was calculated to give an indication of how much variance there is between the Level-2 units. The results of the ICC analysis indicated that only 0.09% of the variance in Peak achievement could be explained at the LDC-level, therefore we did not proceed with further analysis. The results of the ICC analysis indicated that 10.26% of the variance in Cumulative achievement could be explained at the LDC-level, therefore we proceeded with further analysis.

3.7 Results

The analysis presented in this section pertains to only the Net Cumulative Energy Savings Target (Cumulative Target).

Unconstrained Model. We began by examining spatial bias without using any Level-2 (LDC) predictors. Results from this null model (see Appendix D1: Model 1, Null) revealed significant[19] fixed effects on Cumulative Target achievement (β_{00} = 72.78, t(2.45) = 29.73, p < .001). The random effects part of the model also showed significant variability in cumulative target achievement: between-LDC variance (r_{00} = 135.03) and within- LDC variance[20] (e = 1180.75), p = 0.006. The Intraclass Correlation (ICC) value of 0.1026 indicates that 10.26% of the variation in Cumulative Target achievement is attributable to LDC (Level-2), whereas approximately 90% of the variation is within-LDC, longitudinally (Level-1). That is, progress year-to-year in terms of Cumulative Target achievement is more attributable to variation over time rather than to a stable factor or characteristic at the LDC-level. In addition, the variance across time is restricted at Level-1 for cumulative data, since the dependent variable can only remain stable, or increase in value as time progresses. This large clustering effect confirms the identification of longitudinal data as hierarchical, and that the Cumulative Target achievement by LDCs cannot be treated as independent (Luke, 2004).

Effects of time. Next, we analyzed the effect of time (see Appendix D2: Model 2, Time1RE), modelling both linear and quadratic-time at Level-1. Results from this model revealed significant fixed effects of time on Cumulative Target achievement at both the intercept (β_{00} = 109.28, t(3.69) = 29.56, p < .001) and slope (β_{00} = 97.73, t(4.17) = 23.40, p < .001). Note that time was coded in reverse chronological order, so that the intercept represents achievement in 2014, the last year of the period under study. The model also showed significant random effects of time (see Appendix D3: Model 3, Random Effects) on Cumulative Target achievement at both the intercept (r_{00} = 918.15, t(30.30) = 1111.19, p< .001) and slope (r_{01} = 950.31, t(30.83) = 306.57, p < .001) at Level-1. Quadratic time was not significant at Level-1, and thus was removed from the model.

LDC-level predictors. Next, we analyzed eight predictors, including the Peak and Cumulative Targets as control variables at Level-2 (see Appendix D4: Model 4, ZCustDM). The predictor variables were standardized (denoted by the 'Z' preceding the name) to allow for comparison of relative impact on the dependent variable. The correlation matrix for the dataset, generated in SPSS, informed the order in which variables were entered, although all possible permutations were evaluated (see Table 7).

In the OEB dataset, four LDCs did not have complete Level-2 data for the independent variables of interest for all four years of the framework (this was due to missing data in reports submitted to the OEB). The four LDCs that were missing data at Level-2 were: Chapleau Public Utilities Corporation, Cooperative Hydro Enbrun Inc, EnWin Utilities Ltd., and Fort Frances Power Corporation. In order to maximize the statistical power of the model and keep the LDCs with

[19] The term 'significant' is used in the Results section is to denote statistical significance, as indicated by the p-values provided for each test. The implications of these theoretical findings to policy and practice will be expanded upon in the Discussion section of this paper.

[20] The random effects values are not to be taken as absolute values (i.e., standard deviation of the between- and within-LDC cumulative achievement values). Rather, these values were used to calculate the model deviance. In subsequent models (i.e., when predictor variables are added), a comparison of deviances was used to determine model fit and support (or reject) the retention of the null hypothesis (Raudenbush & Bryk, 2002).

missing data at Level-2 in the analysis, regression imputation was used to predict the observed values of the missing variables, based on the available data for each LDC, and the resulting model was then used to impute values into cases with missing data. In addition, three LDCs did not have complete Level-1 data (i.e., had data for only 1 to 3 of the framework years, due to mergers and acquisitions). The three LDCs that were missing data at Level-1 were: Chatham-Kent Hydro Inc., Parry Sound Power Corporation, and Port Colborne Hydro Inc. These LDCs were excluded from the analysis.

Results from this model revealed significant fixed effects of customer density on Cumulative Target achievement at the intercept ($\beta_{01} = 4.07$, $t(1.36) = 3.00$, $p < .001$) at Level-2. Customer density was not significant at the slope at Level-2 and thus was removed from the model. There were no other independent variables that had significant fixed effects on Cumulative Target achievement at the intercept or slope at Level-2.

Combined model. In the final step, we combined the significant Level-1 and Level-2 predictors into a single model. The variable customer density was still a uniquely and statistically significant predictor of Net Cumulative Energy Savings target achievement. This final model improved the model fit from $X^2(1) = 5.42$, $p = 0.019$ to $X^2(2) = 14.102$, $p = 0.001$, and demonstrated that the selected variables have explained 92% of the Level-1 variance and 8% of the Level-2 variance, respectively. However, the error terms are still large and significant, indicating that there remains a significant amount of unexplained LDC-level variance and especially longitudinal variance on cumulative target achievement.

Table 7: Correlation Matrix

	1	2	3	4	5	6	7	8
1 Time	1	-.959**	0.012	-0.025	0.027	.346**	.666**	0.08
2 Time (Quadratic)	-.959**	1	-0.012	0.02	-0.025	-.328**	-.632**	-0.075
3 Total # of customers	0.012	-0.012	1	.134*	.156**	.137*	0.027	-0.011
4 Debt-equity ratio	-0.025	0.02	.134*	1	-0.014	-0.022	0.101	0.045
5 Customer Density	0.027	-0.025	.156**	-0.014	1	.274**	-0.083	-0.066
6 Total cost per customer	.346**	-.328**	.137*	-0.022	.274**	1	.351**	-0.09
7 Total cost per kW	.666**	-.632**	0.027	0.101	-0.083	.351**	1	0.021
8 Customer mix	0.08	-0.075	-0.011	0.045	-0.066	-0.09	0.021	1

** Correlation is significant at the 0.01 level (2-tailed).

* Correlation is significant at the 0.05 level (2-tailed)

The estimated HLM model for Net Cumulative Energy Savings Target Achievement that best fit the case study data (Full Maximum Likelihood was used to develop the model) was:

Level 1: $CUMULATI_{ti} = \pi_{0i} + \pi_{1i}*(TIME1RE_{ti}) + e_{ti}$

TIME is an uncentered variable

Level 2: $\pi_{0i} = \beta_{00} + \beta_{01}*(ZCUSTDEN_i) + r_{0i}$

$\pi_{1i} = \beta_{10} + r_{1i}$

ZCUSTDEN has been centred around the grand mean[21].

Mixed model: $CUMULATI_{ti} = \beta_{00} + \beta_{01}*ZCUSTDEN_i + \beta_{10}*TIME1RE_{ti}$

$+ r_{0i} + r_{1i}*TIME1RE_{ti} + e_{ti}$

The estimates for the final model (completed using Restricted Maximum Likelihood) can be seen in Table 3. These results provided some support for our predictions regarding the use of conventional benchmarking inputs to explain the variability in CDM target achievement, and the rate of change towards CDM targets over time. As a first starting point for testing this hypothesis, this model revealed that for the case study, there was significant change in both the Net Cumulative Energy Savings Target (intercept) and the rate of change towards the target (slope), within LDCs at Level-1, and between LDCs at Level-2, both at the $p<0.001$ level. This is a finding in and of itself. Thus, the exploration of factors that can explain the variability has been empirically justified.

In the literature review, it was posited that conventional benchmarking inputs might explain the variability in target achievement and the rate of change towards the Net Cumulative Energy Savings target. Of the eight independent variables tested, one – customer density – was a significant predictor of cumulative energy target achievement at Level-2. Customer density was a significant predictor of the model intercept, which was the average percentage of Net Cumulative Energy Savings achieved in 2014, the last year of the CFF program. The final model revealed an intercept value of 109.28%, which was the mean achievement of the Net Cumulative Energy Savings Target in 2014. As outlined in the descriptive statistics presented in Table 6, the standard deviation for Net Cumulative Energy Savings in 2014 was 33.82%, with a minimum value of 37.16% and a maximum value of 226.87% (the mean was calculated to be 109.93%). The standard deviation for customer density was 240.80 (# of customers per sq. km of service area), with a minimum value of 0.82 and a maximum value of 1,181.35. In the final model, the standardized coefficient of 4.07 indicates that for every increase of one standard deviation in customer density, an LDC's achievement of the Net Cumulative Energy Savings target rose by 4.07%. The positive value of the coefficient indicates that there is a positive relationship between the two variables, such that a higher customer density is correlated with a higher percentage achievement of the cumulative target. In other words, there is a statistical difference in the percentage achievement of the cumulative target in 2014 between LDCs with

[21] The grand mean is the overall mean for all LDCs (i.e., the Level-2 mean). In contrast, the group mean is the mean for each individual LDC over the framework period (i.e., the Level-1 mean for each LDC).

higher customer density (number of customers per square kilometre of LDC service territory) than those with lower customer density.

While none of the benchmarking inputs tested were significant predictors of the rate of change towards the Net Cumulative Energy Savings target, it is notable that there are both significant fixed and random effects, thus it should be possible to improve the predictive power of this model using other independent variables.

Table 8: Hierarchical longitudinal model of Cumulative Target Achievement (linear time variable coded in reverse chronological order, Intercept = Net Cumulative Energy Savings Target Achievement in 2014)

Parameter	**Estimated Coefficient**	**SE**	**p-value**
Fixed effects			
Intercept, β_{00}	109.28	3.60	<0.001
Customer density (standardized), β_{01}	4.07	1.36	0.004
Slope (Time), β_{10}	97.71	4.16	<0.001
Variance components			
Level-1, e	90.88	9.53	
Intercept, r_0	885.72	29.76	<0.001
Time Slope, r_1	967.74	31.11	<0.001
Restricted Maximum Likelihood estimation			
Intraclass Correlation Coefficient	10.26%		

While the correlation matrix (Table 7) did not reveal any inter-correlations between the predictors that caused concern regarding the independence of variables, it is plausible that the variables chosen were closely related enough that adding more variables could not explain additional variance. For example, the total number of customers is intuitively related to customer density and customer mix. Therefore, adding additional predictors to the model after accounting for customer density did not improve the model fit. Nevertheless, this analysis serves as a starting point for explaining the performance of Ontario's LDCs with respect to the province's CDM targets.

3.8 Discussion

Given the statistically significant variability among LDCs' achievement of their Net Cumulative Energy Savings target (variance of intercept) and in the rate of LDCs' movement toward the target over time (variance in time slope), there is a need to better understand what factors may predict these variances so that LDCs that did not achieve their target can be supported and the conditions for their success be improved. In parallel to the economic efficiencies demonstrated in the econometrics

literature on the benchmarking of electricity distributors, it was posited that conventional benchmarking inputs might explain the variability in target achievement and the rate of change towards the Net Cumulative Energy Savings target. This study sought to determine whether some LDCs are better suited than others to secure conservation behaviour from their customers, based on their economic productivity. As in any jurisdiction where large amounts of taxpayer dollars are being spent on energy efficiency initiatives, an increase in program effectiveness (and decreased variation in the performance outcomes) would have benefits for many groups of stakeholders in Ontario, and the environment more broadly.

The findings from this study offer some insight into the government of Ontario's $1.8 billion investment into CDM programs from 2011-2014. Based on this analysis, LDCs with higher customer density were more likely to achieve their Net Cumulative Energy Savings target than LDCs with lower customer density. As in conventional performance benchmarking, a higher customer density is associated with a lower cost of unit service delivery. Therefore, an inference can be made that a lower cost of unit service delivery may be associated with greater ability to achieve energy savings. However, no mechanism for this relationship was unearthed from this case study. This study made use of publically available data published by the Ontario Energy Board. Further research is required to determine what factors can explain the statistically significant variability in the LDCs' achievement of their Net Cumulative Energy Savings target, and their rate of change toward the target over time.

3.8.1 Limitations

While the Ontario Energy Board's Yearbooks of Electricity Distributors (2011-2014) contained detailed information on the financial and operational performance of the LDCs, the results of this study clearly indicate that there are other important factors in explaining the variability of energy conservation performance and the rate of change towards energy conservation targets by the LDCs. The biggest limitation of this study was that the predictor variables were limited to the publically available data, which focused on financial and operational benchmarking metrics and did not include any metrics on other potential predictors of energy conservation performance, (e.g., the extent of integration of sustainability into corporate strategy of an LDC).

The use of cumulative data in the dependent variables of interest also limited the range of data being analyzed, and thus by default, the variability that could be analyzed by a statistical model. As was seen in Section 5.1, there was not enough variability in the data between the LDCs (Level-2 units) to estimate the statistical significance of the variability in the Net Annual Peak Demand Savings target achievement or the rate of change towards the target between the LDCs (Intraclass Coefficient, ICC of 0.09%). However, despite the limiting nature of cumulative data, there was sufficient variability between the LDCs (ICC of 10.26%) to analyze the achievement of Net Cumulative Energy Savings target as a dependent variable.

3.9 Conclusion and Policy Implications

This study has examined the determinants of electric distribution utilities' achievement of peak and cumulative targets as part of a government-funded energy efficiency and conservation program at the provincial level. Using data from 2011-2014, this study tests whether the variables used to benchmark the operational efficiency of electricity distribution utilities can also be used to predict their relative 'success' with respect to conservation and demand management. The results show that in the Ontario context, customer density significantly predicts the achievement of an LDC's net cumulative energy savings target. No other tested variables were statistically significant. It was not possible to model the LDCs' achievement of the peak demand target, due to insufficient variability in the data. It is also important to note that since there was no annual re-assessment of the targets during the CFF program from 2011-2014, any deductions from these results about whether these targets were disproportionately 'easier' for some of Ontario's LDCs to achieve are inferential. Future research could include repeating this analysis for the second CFF period, 2015-2020, to determine whether the model fit can be improved with additional variables.

Based on this case study, conventional benchmarking metrics appear to have limited value in predicting conservation performance. According to the multi-level model that was analyzed, 90% of the variance in conservation performance was within each LDC (i.e., at Level-1) and only 10% of the variance was between LDCs (at Level-2). However, much of the observed variance is due to the cumulative nature of the dependent variable, therefore this result may be compounded. The statistically significant variance of the rate of change over time demonstrates that LDCs are moving towards their respective targets at different rates, and this variance was unexplained by the multi-level model developed in this case study. Therefore, opportunities remain to improve the model and offer further insight into Ontario's energy conservation landscape.

Future research could include developing a new model, based on Level-1 data, such as program-specific (e.g., residential demand response, business energy audits, industrial energy manager, etc.) annual spending metrics: program administration budget (PAB), participant based funding (PBF), participant incentives (PI), or Capacity Building Funding (CBF). This analysis may also point to a need for the OEB to monitor, measure, and publicly report additional performance metrics that may be more relevant to LDCs' achievement of CDM targets. For example, achievement of CDM targets may be more closely linked to expenditures on conservation initiatives focused on commercial or residential customers, or on collaborations between LDCs with respect to infrastructure renewal, as opposed to the conventional metrics that benchmark operational performance. The challenge is that the data potentially needed for the CDM benchmarking of LDCs are not currently publicly available at the level of detail required. There is also a lack of empirical evidence investigating the CDM performance of electric utilities, thus limited literature support for additional spending to measure and monitor data that may (or may not) explain achievement in this area.

Future research could also draw potential predictor variables from other sectors that are interested in achieving energy efficiency, such as the commercial real estate sector, for a cross-disciplinary

perspective. For example, in the commercial buildings literature, energy efficiency performance outcomes (e.g., investment in building retrofits) have been linked to organization-level variables such as the demonstrated commitment of organizational leadership to environmental stewardship and corporate social responsibility (e.g., Gliedt & Hoicka, 2015; Dumitru et al, 2016; Hejjas, Miller, & Scarles, 2018), employees' trust in leadership and their environmental commitment (Inoue & Alfaro-Barrantes, 2015; Paillé et al, 2016), and the overall energy consumption culture within an organization (Endrejat et al, 2015). Based on this literature and recent empirical research, economic benefits alone are insufficient to explain energy performance behaviour. Organizations within the commercial buildings sector are also motivated to achieve efficiency outcomes through mechanisms that generate indirect benefits such as green building image and corporate identity, which can be leveraged through corporate branding and stakeholder engagement (Whitney, Dreyer, & Riemer, in press). Future research could explore these factors within the context of an LDC to determine if they have explanatory power with respect to achievement of energy targets.

In their econometric benchmarking model of electricity utilities in the United States, Fenrick & Getachew (2012) observe that the competitive motivation to increase service quality through efficiency to attract and retain customers is not present, due to the monopoly or near monopoly status of most utilities. While Ontario's case is similar, the LDCs operate in a highly regulated and transparent system, and are arguably driven to continuously improve their performance through the public reporting process. It remains to be seen whether performance of the Ontario's LDCs in the current framework (2015-2020) will be significantly improved beyond the 2011-2014 framework, and it is notable that the current 2015-2020 framework does not include a peak demand target. Being able to explain the achievement of CDM performance at the utility level would allow for the adoption of the exemplary characteristics by LDCs that did not achieve the targets, and would ultimately support the Minister of Energy and Infrastructure's goals of achieving greenhouse gas emissions reduction from reduction of electricity consumption in Ontario.

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Chapter 4 – Motivations and barriers to energy management in office buildings: A qualitative study

"[...] vision without systems thinking ends up painting lovely pictures of the future with no deep understanding of the forces that must be mastered to move from here to there."

— Peter M. Senge, The Fifth Discipline: The Art & Practice of The Learning Organization

4.1 Introduction

Mitigating climate change and reducing greenhouse gas emissions is widely recognized as a key challenge of the 21st century. Since buildings account for approximately 40% of global energy use and 38% of global GHG emissions (UNEP, 2012), there is great potential for emissions reduction from this sector. In Ontario, Canada, the Ministry of Environment's Climate Change Action Plan (CCAP) estimates that 50,245,000 tonnes of GHG emissions reductions can be achieved through the buildings sector by 2050, at a cost of $96/tonne (Government of Ontario, 2018). Low-carbon building projects – including retrofits, green construction and building operations, are one of six key initiatives that will receive long-term government funding in order to support and enable long-term GHG emissions reductions in the province (Government of Ontario, 2018). The Independent Electricity System Operator (IESO) has also prepared an Achievable Potential Study, outlining the potential of various activities to contribute to the province's electricity conservation goals. The commercial sector is highlighted in this study as having the greatest potential for emissions reduction, given existing technologies that are commercially available (IESO, 2014). In Canada, commercial buildings account for approximately 36% of the nation's energy use (Natural Resources Canada, 2014).

Building retrofits can be considered climate change mitigation activities, defined as "substantive physical changes to a building or buildings to improve energy efficiency" (Dixon, 2014, p. 444). There is evidence of increased investment in building retrofits globally, with $133 billion being spent on energy efficiency in buildings in 2016 (International Energy Agency, 2018). However, the combination of slow policy progress (IEA, 2018) and retrofit under-investment in the commercial real estate market (Dixon, 2014) puts future energy efficiency gains and GHG emissions reductions at risk. In addition, there is a pervasive 'performance gap' between targeted and actual energy use within buildings (the former being based on technological and economic potential, while the latter is based on market behaviour), even in retrofitted or new high-performance buildings (e.g., Allcott & Mullainathan, 2010; Jaffe & Stavins, 1994; Wilson & Dowlatabadi, 2007). This gap is largely attributed to the decision-making of individuals and organizations that occupy buildings and use energy services, resulting in both market and non-market failures (e.g., De Wilde, 2014; Jaffe & Stavins, 1994; Wilson & Dowlatabadi, 2007). As such, reducing energy consumption in commercial buildings through changes in workplace behaviour is seen as an important area of academic research (Andrews & Johnson, 2016; Schelly et al, 2011; Zhang et al, 2013). In a recent case study of an innovative, high-performance building that failed to deliver the expected energy savings, Fedoruk et

al. (2015) emphasized the importance of understanding and addressing institutional norms that may impede the performance of energy systems within a building, and establishing meaningful and effective building energy monitoring capabilities and feedback processes throughout all stages of the building lifecycle.

This paper aims to contribute to knowledge by investigating the performance gap in commercial office buildings (and opportunities to reduce it) through a systems lens, seeking to: 1) understand the motivations and barriers for key stakeholders (through interviews of a targeted sample population) to engage in sustainable energy management practices within the systems context; and 2) identify leverage points within the system for intervention, in order to reduce the performance gap.

4.2 Literature review

Meadows (2009) describes a system as "a set of things - people, cells, molecules, or whatever - interconnected in such a way that they produce their own pattern of behaviour over time" (p. 2). This description provides a useful conceptualization of a commercial office building, which considers the physical structure, multiple actors, and the temporal relationships among all system components. Expansion of this description reveals that a system is "more than the sum of its parts" (p. 12); function or purpose (including ensuring system perpetuation) distinguishes systems from a collection of related items, along with the exhibition of "adaptive, dynamic, goal-seeking, self-preserving, and sometimes evolutionary behaviour" (p. 13) in the pursuit. As systems are hierarchical and nested – for example, organizations that occupy commercial office space are systems in themselves – the true purpose of any given system is deduced from observing system operation and behaviour, rather than explicit rhetoric (e.g., the stated mission of an organization).

In the remainder of this section, an overview of a commercial building as a system – (physical and human) components, interconnection, and purpose will be presented.

4.2.1 Physical components - Commercial buildings

In its 2017 Global Status Report, the United Nations Environment Programme (UNEP) estimated that the fossil fuel used in the operation of buildings contributes more than one-third of total global GHG emissions (UNEP, 2017). It is widely recognized that energy consumed in the operation of a building, during its useful lifespan, can be significantly impacted by the design and construction of the building envelope – the energy efficiency of exterior walls, windows, external doors, roof, and floor (e.g., Lawania & Biswas, 2016). Therefore, transitioning to a low-carbon future requires innovative design practices that incorporate low-energy and carbon intensive materials in the construction of buildings to minimize a building's footprint and also to reduce energy consumption during the operation and occupancy stage (Fedoruk et al., 2015; Lawania & Biswas, 2016). Technological advances have made it possible to reduce buildings' negative impacts on the environment using sustainable building practices, and rating systems and certification programs provide guidance and tools to facilitate the design and construction of high performance green buildings (Khashe et al., 2015).

At the national level, commercial buildings account for one-fifth of annual energy use[22] in the USA (US EIA, 2018), while commercial and institutional buildings collectively account for 10% of annual energy use in Canada, and 9% of the country's total GHG emissions (NRCan, 2016). Energy consumption and use in commercial buildings is the cumulative result of the performance and efficiency of technologies in place and a host of other factors including (but not limited to) energy prices, social and behavioral factors, and building management strategies (Gliedt & Hoicka, 2015). There is a vast and growing body of literature on the environmental benefits of residential and commercial energy efficiency, given the contribution of daily consumer and corporate activities to greenhouse gas (GHG) emissions (e.g. Abrahamse & Steg, 2011; Andrews & Johnson, 2016; Clune, Morrissey, & Moore, 2012; Lo, Peters, van Breukelen, & Kok, 2014). This literature includes a substantial amount of Canadian and North American research, more broadly, with investigation of both energy consumption behaviour, and the motivations and barriers to more sustainable behaviour (e.g. Cuddy, Doherty, & Bos, 2012; Gliedt & Hoicka, 2015; Newsham & Donnelly, 2013; Senbel, Ngo, & Blair, 2014). This academic interest in attitude, values, and behaviour acknowledges the interconnectedness of the physical and human aspects of a building, as flows of information and feedback processes within the system change both behaviour patterns and the system outcomes (Meadows, 2008). Feedback loops produce behaviour patterns over time through causal, closed chains of events related to the level of a component within a system. Reinforcing feedback loops enhance or amplify the direction of change imposed (e.g., increasing the number of building retrofits will increase the energy efficiency of a building, as denoted by the positive "+" notation beside a loop section), while balancing feedback loops oppose the direction of change imposed, seeking to stabilize a system (e.g., increasing capital cost of retrofits will reduce the number of building retrofits, as denoted by the negative "-" notation beside a loop) (Meadows, 2009).

4.2.2 Human components - Stakeholders and interconnections

A considerable body of literature has positioned employees or building tenants as the segmented groups of interest, focusing on how to engage them in pro-environmental behaviour (PEB) and bridging behavioural intention and action (Blok et al, 2015; Greaves et al, 2013; Lo et al, 2014; Miller & Buys, 2008; Norton et al, 2017). Studies have shown that employees are motivated by personal norms, influenced by biospheric values and environmental self-identity (Ruepert et al., 2016), perceived importance of sustainability to their organization, and specifically, their upline manager (Young, 2015). The importance of sustainability issues to an organization as perceived by employees can be demonstrated by incentives, support from peers and leadership for performing related tasks, and provided training and education (Manika, 2013; Paille, 2016; Young, 2015). Empirical studies have shown that when upline managers and executive leadership demonstrate voluntary PEB in the workplace, there are cumulative and amplified consequences within work groups in office buildings (e.g., heightened moral reflectiveness) (Kim, 2017). Conversely, when organizational procedures signal the prioritization of economic profitability through profit-based

[22] Based on the 2012 Commercial Buildings Energy Consumption Survey (CBECS). The EIA is in the process of planning the next CBECS. The data collection period will begin in April 2019, gathering information for reference year 2018.

rewards, employees are more likely to narrow their focus to cost minimization behaviours (Ruepert et al, 2016). Other barriers to employee PEB include an overall lack of knowledge about the implications of actions and poor understanding of high-performance technology and building performance outcomes (Miller & Buys, 2008).

Specifically within workplaces, research suggests that mid-level managers are key in supporting the mission and policies on environmental sustainability and can facilitate employee's intrinsic motivation for pro-environmental behaviours (PEBs) by fostering an autonomy-supportive work climate (Pelletier & Aitken, 2014) (Gagné, Pelletier, & Aitken, 2014; Pelletier, Lavergne, & Sharp, 2008). 'Pure' intrinsic motivation, where behaviour comes from self-interest, enjoyment, and inherent satisfaction, is the ideal type for satisfying the needs for competence, relatedness, and autonomy (Ryan & Deci, 2000). Intrinsic motivation also allows individuals to experience well-being, and place more emphasis on intrinsic aspirations, such as affiliation, personal growth, and community, versus other goals that do not directly contribute to (and may even detract from) the basic needs, such as extrinsic aspirations of wealth, fame, and image (Ryan & Deci, 2000). Extrinsic motivations fail to sustain PEB in the long-term, because once incentives or punishments (for performing or failing to perform) are removed, behaviour will only continue if individuals are self-determined (Pelletier 1999; 2000).

One segment of stakeholders that has received less attention in academic research, at least with respect to reducing energy consumption, are building owners, property managers, and operators. Researchers have acknowledged the critical role that these stakeholders play in making decisions about building retrofits (Gliedt & Hoicka, 2015) and offering energy efficient products and services (Devine & Kok, 2015). Owners have been shown to be motivated to invest in commercial building retrofits by a combination of financial benefits (improved asset value, cost savings, good return on investment) and ancillary benefits, such as leveraging competitive advantage for the corporation and buffering rising energy prices (Gliedt & Hoicka, 2015; Dixon 2014). Retrofits beyond regulatory compliance standards in some cases were limited to newer properties in desirable office locations (Elliott et al., 2014). Barriers for building owners to invest in retrofits include economic cost/benefit analysis with payback periods of greater than five years, lack of access to capital when retrofit projects must compete with other core business expenses, and split-incentive issues (Dixon, 2014; Kontokosta, 2016). Opportunities for retrofit investments have also been tied to the lifecycle of equipment and timing of repairs to critical components (Kontokosta, 2016). While building tenants are increasingly expecting sustainability features within rented office space, and in some cases are willing to pay premiums (or take "non-sustainability" discounts), an expectation remains that the building owner assumes the risk of the financial investment, receiving tangible benefits of increased occupancy rates, increased rental rates, and intangible benefits of increased likelihood of lease renewal, tenant satisfaction (Miller & Buys, 2008; Devine & Kok, 2015).

Commercial building retrofit activity "has been hampered by actual and perceived barriers that have limited the widespread adoption of energy conservation measures" by building owners and managers (Kontokosta, 2016, p.12). Likewise, employees in workplace settings require a "volitional sense of

attachment and responsibility" in order to partake in voluntary energy conservation behaviour, unless they have very strong personal environmental beliefs (Raineri & Paillé, 2016, p. 142). In these contexts, researchers have highlighted the need to 'break down barriers' and discuss shared benefits between stakeholders in order to address principal-agent issues and achieve more sustainable commercial buildings (Axon, Bright, Dixon, Janda, & Kolokotroni, 2012; Greenough & Tosoratti, 2014; Martin & Gossett, 2013). There is limited empirical research investigating buildings as systems, with the exception of living laboratory settings in the residential context (e.g., Schwartz, Denef, Stevens, Ramirez, Wulf, & Augustin, 2013), although Fedoruk et al. (2015) have moved in this direction with their examination of the performance of the Centre for Interactive Research on Sustainability (CIRS) building at the University of British Columbia (UBC).

4.2.3 Purpose - Reducing the performance gap

To address this gap, this paper proposes that a systems framework is required to integrate perspectives of the different stakeholders that are invested in the ownership and use of commercial buildings, in order to understand the leverage points for reducing the performance gap. This viewpoint aligns with Karlsson-Vinkhuyzen, Jollands, & Staudt's (2012) systems conceptualization of an energy system with the following components:

1. The infrastructure needed to extract, transport, transform and use energy;
2. The physical impacts[23] on the environment and people of energy extraction, transport, transformation and use;
3. The social institutions (such as international agencies, governments and the regulatory frameworks, markets and civil society groups) designed to support the flow of energy services; and
4. The individual actors involved in using energy services, within the system (Karlsson-Vinkhuyzen et al., 2012).

Following this conceptualization, and narrowing the inquiry to commercial buildings where energy is used (as per Section 2.1), the performance gap represents a physical impact on the environment, and both the governing social institutions and individual actors that manage and use energy services can influence the impact[24]. Changing the behaviour of the individual actors (and over time, the governing social institutions) are then pathways to achieving the desired system-level outcome of reducing the physical impacts of the system. A few conceptual frameworks have been developed to effect change within social systems. Parsons (2007) proposes that Complex Adaptive Systems theory can be used to model how individuals or organizations make intentional changes in stable system conditions, and also how they self-regulate and learn under uncertainty. Foster-Fishman, Nowell, & Yang's (2007) system of change framework emphasizes the process of stakeholder engagement in the initial assessment and design stages of a systems change, focusing on engagement as a transformative end that supports the systems change goals. In their diagnosis of transformative

[23] The authors cited have adopted the 'public good' framing, where impacts include outcomes such as air pollution.
[24] Adoption of existing technologies is considered a decision made by individuals, as per Allcott & Mullainathan (2010).

change in urban water systems, Ferguson, Brown, & Deletic (2013) analyzed five frameworks – 1) the Social–Ecological System (SES) Sustainability Framework; 2) the Ecosystem Stewardship Framework; 3) the Panarchy Framework; 4) the Multi-Pattern Transitions Framework; and 5) the Management and Transitions Framework – and determined that all offered explanatory value or useful insights for strategic action, depending on the aim/problem, and the prioritization of the system conditions. For the purpose of this paper, rather than formally adopting a conceptual framework, a more general premise that "the behaviour of a system arises from its structure" (e.g., Laurenti, Singh, Sinha, Potting, & Frostell, 2016, p.382; Meadows, 2009) has been adopted. As such, this research focuses on the modes of behaviour that are created by the interactions between the physical and human components of the commercial building system (Forrester 1961 and others, cited in Laurenti et al., 2016), which then lead to system change.

4.3 Context for the current study

This study applies systems thinking to characterize energy management decision-making in commercial office buildings, using a Canadian sample population. In this context, the research questions addressed in this study are:

1. What are the physical and human components and the relevant interconnections between the components of the system in the investigation of a commercial office building's performance gap?
2. What are the modes of behaviour or pathways that influence the energy management decisions of the major stakeholders within the system of a commercial office building?
3. What characteristics within the system could be leveraged to reduce the performance gap in a commercial office building?

4.3.1 Deductive conceptualization of influences

Based on the literature review, the context or unique circumstances that shape events, actions and meaning for the stakeholders (Maxwell, 1996) in which stakeholders operate was deductively conceptualized (Creswell, 2009), four broad themes were hypothesized to influence energy management practices in commercial buildings: Built Environment, Leadership Context, Stakeholder Engagement, and External Drivers. These themes, detailed in Table 9 and illustrated in Figure 16, were used as a framework for exploring the research questions and developing the interview protocol (described in Section 4.2.2). In establishing the broad themes, an effort was made to ensure alignment with Karlsson-Vinkhuyzen, Jollands, & Staudt's (2012) systems conceptualization of an energy system.

Table 9: Conceptualization of themes that influence energy management decision-making in commercial buildings (based on literature review)

Theme	**Definition and Literature Support**
Built Environment (Physical components or Infrastructure)	The built environment is, simply put, the existing building stock. Axon et al. (2012) further describe the building stock to include: age, condition, use, etc. According to the Centre for Education in the Built Environment (2011, cited in duToit & Mouton, 2013), 'built environment' refers to disciplines such as architecture, urban design, urban and regional planning (or just 'planning'), housing, construction, surveying and real estate.
Leadership Context (Human Components, Individual Actors / Social Institutions)	Leadership is the internal demographic context of an organization (Dumitru et al., 2016). With respect to business, the extent to which organizations integrate environmental (or sustainability) practices into their business operations is seen as a leadership initiative, and performance in this regard can be measured and indexed against others (Inoue & Alfaro-Barrantes, 2015b).
Stakeholder Engagement (Individual Actors)	Endrejat et al (2015) distinguishes between individuals that live in the built environment and those that work there (i.e., residential and non-residential). Axon et al (2012) further categorize stakeholders in tenanted commercial properties as: investors, developers, agents, owners, tenants, facilities managers and users of the space (employees and customers). Public acceptance is an absolute requirement for the uptake of any energy initiative, therefore developing effective ways to engage with the public as a stakeholder is becoming more important (Wong-Parodi, Dowlatabadi, McDaniels, & Ray, 2011).
External Drivers (Social Institutions)	Staddon et al (2016) define external factors as: institutional, economic, and social and cultural factors. In the current conceptualization, the internal institution (e.g. the property management firm) is drawn out as a separate theme, called Leadership Context. Other institutions (government, associations, etc.) are included as external drivers.

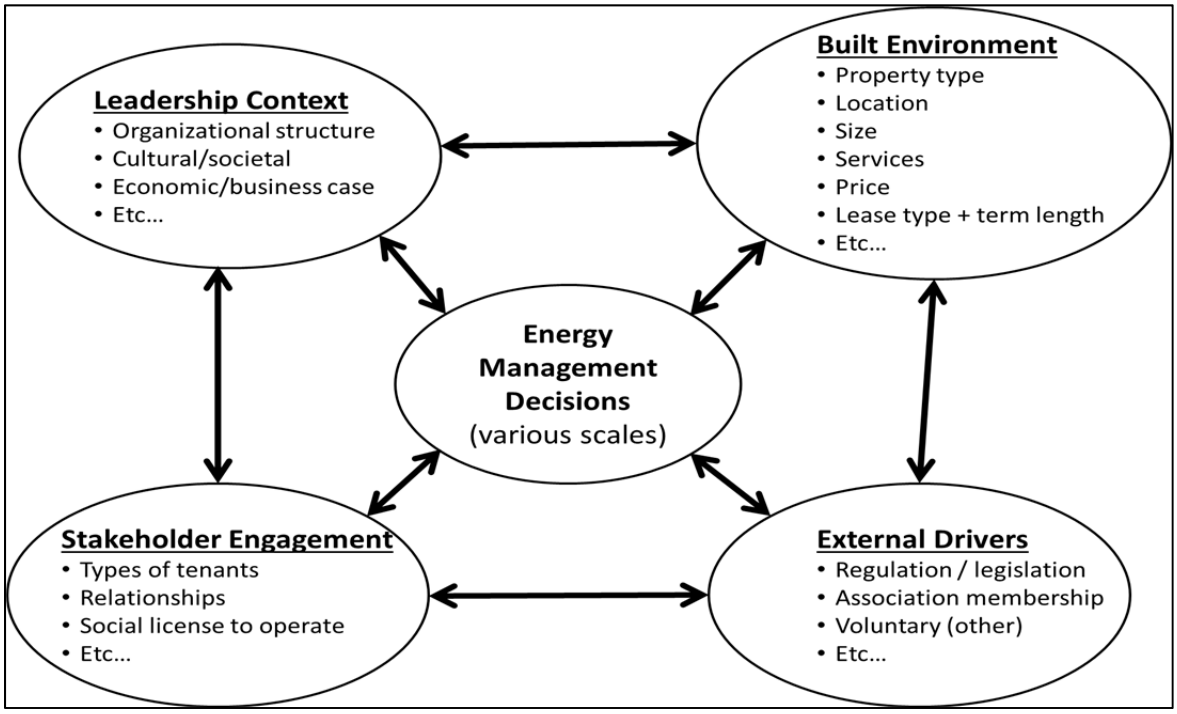

Figure 16: Initial conceptual framework, based on literature review

4.3.2 National energy production and consumption

Energy is produced and consumed differently across Canada due to many factors including (but not limited to) the availability of natural resources, historical infrastructure, industrial structures, energy and environmental policies and regulations, consumer preferences, and weather conditions (NEB, 2018). Figures 17 to 20 are provided to give the reader a sense of the electricity supply, energy demand, potential energy demand growth, and energy-related GHG emissions at the provincial level in Canada.

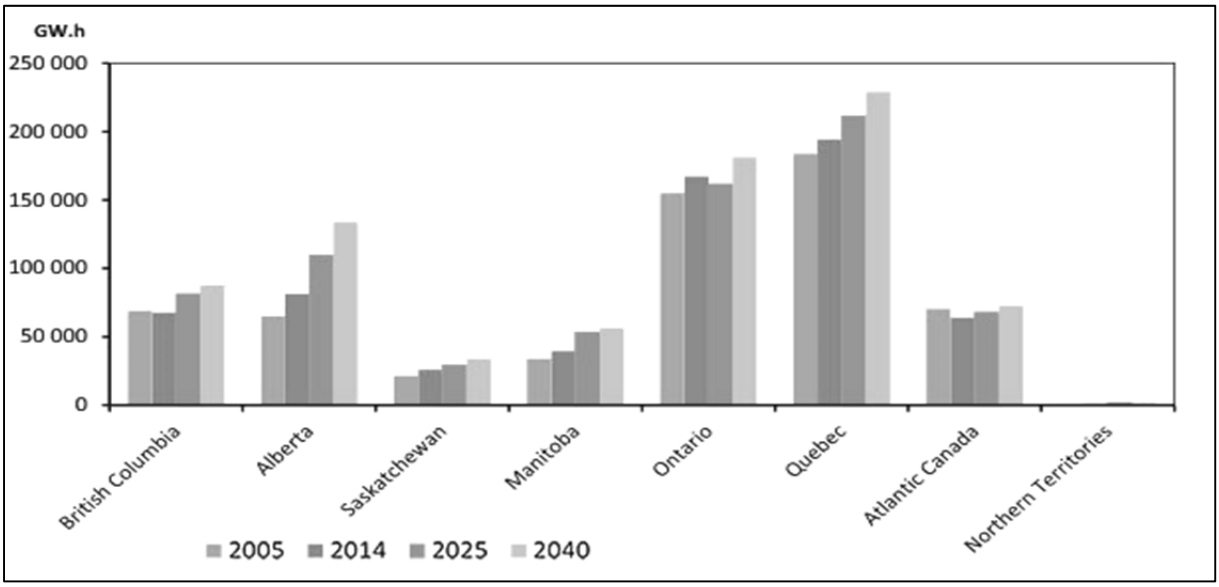

Figure 17: Historic and Projected Electric Generation by Province/Territory (source: National Energy Board, 2018)

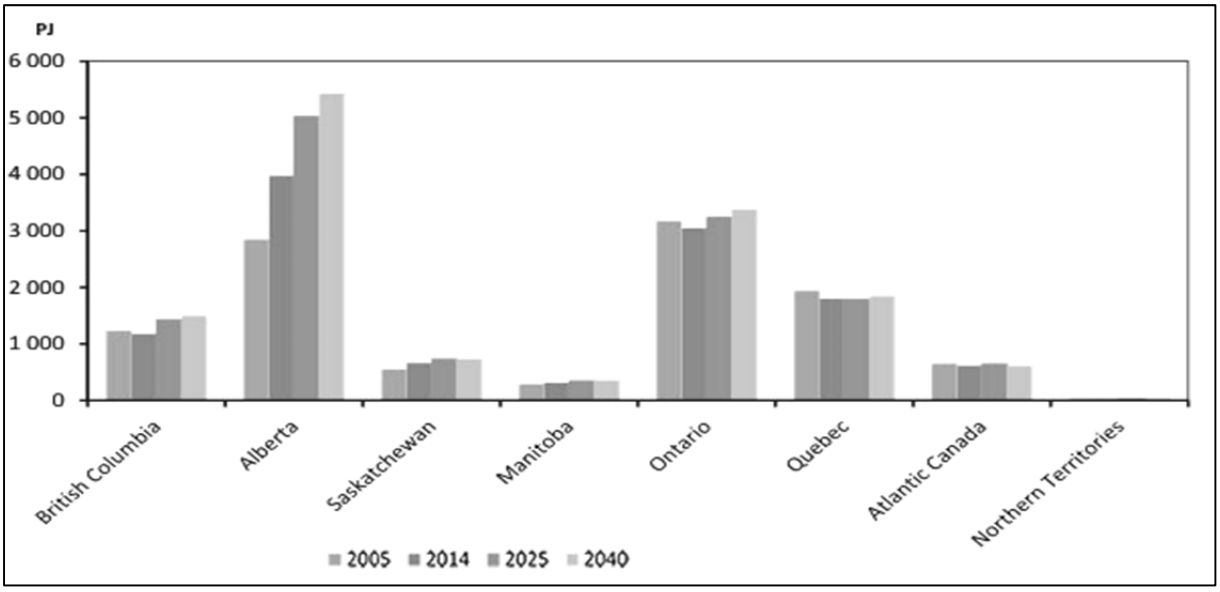

Figure 18: Historic and Projected Energy Demand by Province/Territory (source: National Energy Board, 2018)

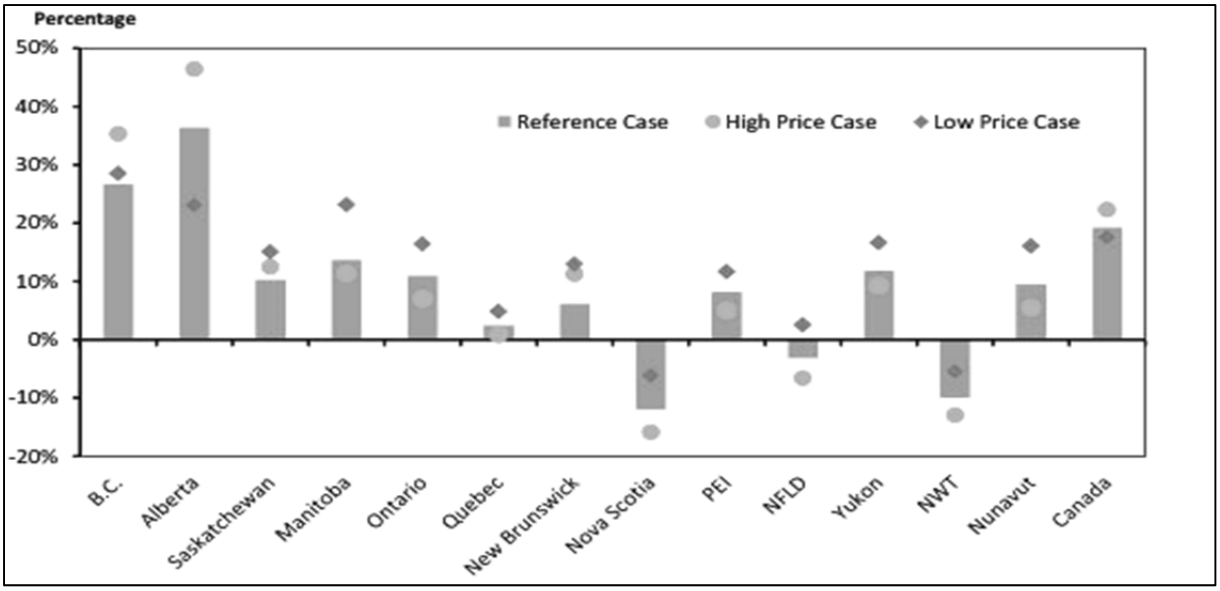

Figure 19: Potential growth in energy demand and price cases, reference case 2014, and projection to 2040 (source: National Energy Board, 2018)

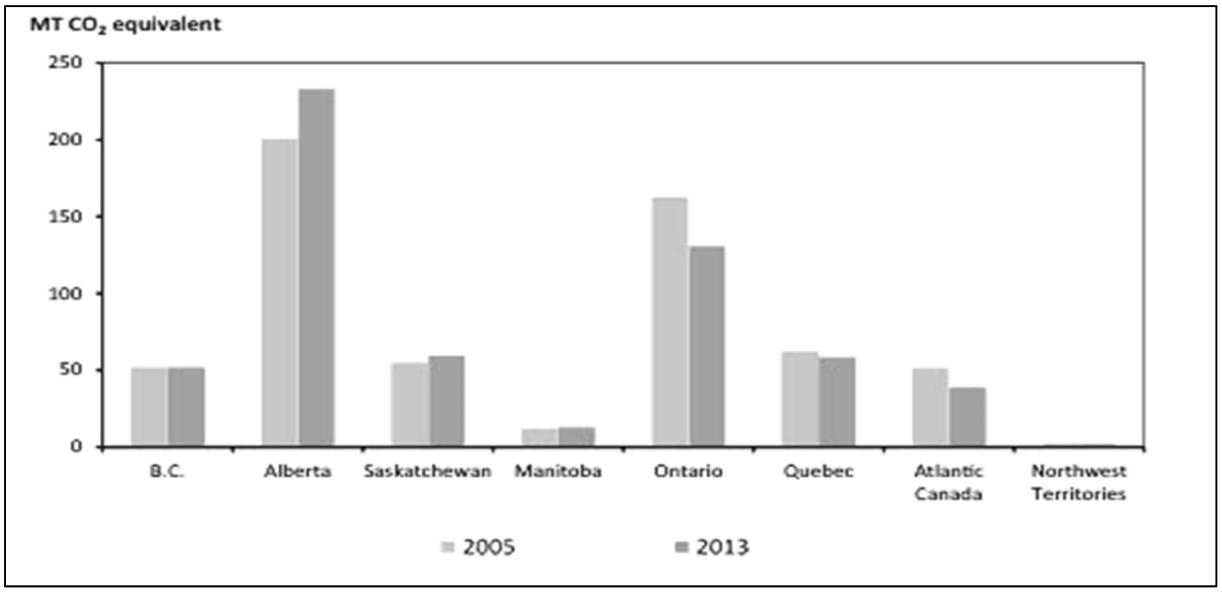

Figure 20: Energy-related GHG emissions by Province/Territory

The key insights gleaned from the national-level data presented above are as follows:

1. Total energy production is expected to grow substantially through to 2040, based on increased oil sands production and liquefied natural gas (LNG) production;
2. The GHG emissions associated with energy production are expected to follow a similar growth trend, unless significant technological innovations and/or more stringent regulations are introduced in order to influence emissions from this sector; and

3. Total energy production is expected to grow faster than domestic energy demand, as exports are a key national driver of economic growth (note: the energy intensity of the Canadian economy is expected to continue its declining trend) (NEB, 2018).

4.3.2.1 Ontario and Alberta

The current study investigates the commercial real estate sector in two Canadian provinces, Ontario and Alberta, to offer distinct jurisdictional perspectives, in addition to the multiple stakeholder perspectives. BOMA Canada, the primary facilitator of the data collection for this study (see Section 4.2) is headquartered in Ontario (Toronto), as are the many of the country's largest property management firms. A brief comparison of the energy landscape of these two provinces is provided in Table 10, with an emphasis on electricity.

Table 10: Comparison on energy landscape, Ontario and Alberta (compiled from data from the National Energy Board, 2018)

2015 Statistics	**Ontario**	**Alberta**
End-use demand, Petajoules (PJ)	3,050	3,630
Largest sectors for energy demand	Industrial (35%) Transportation (29%) Residential (21%) Commercial (16%)	Industrial (73%) Transportation (13%) Commercial (8%) Residential (6%)
Total energy demand	2nd nationwide 9th per capita	1st nationwide 1st per capita
Electricity consumption, Mega-watt hours (MWh)	9.8	19.8
Total electricity consumption	12th nationwide, per capita 35% less than national average	2nd nationwide, per capita 36% more than national average
Largest sectors for electricity consumption	Residential (47.9 TWh) Commercial (47.1 TWh) Industrial (41.7 TWh) *Ontario's electricity demand has grown only 5% since 2005.*	Industrial (52.1 TWh) Commercial (15.1 TWh) Residential (9.9 TWh) *Alberta's electricity demand has grown 19% since 2005.*
GHG emissions Megatonnes (MT) of carbon dioxide equivalent (CO_2e)	166.2 *Ontario's emissions have declined 8% since 1990; the province's per capita emissions are the* 3rd nationwide*, at 12.0 tonnes of CO2e – 40% below the Canadian average of 20.1 tonnes per capita.*	274.1 *Alberta's emissions have increased 56% since 1990; the province's per capita emissions are the 2nd highest nationwide, at 65.6 tonnes CO2e – more than three times the national average of 20.1 tonnes per capita.*
Largest emitting sectors	Transportation (33%) Buildings - residential and commercial (22%) Heavy industries - including iron, steel, and chemicals (12%)	Oil and gas production (48%) Electricity generation (17%) Transportation (12%)
Emissions from electricity sector Megatonnes (MT)	5.2	46.1[1]

[1]Alberta's electricity sector produces more GHG emissions than any other province because of its size and reliance on coal-fired generation. In 2015, Alberta's power sector accounted for 57% of total Canadian GHG emissions from power generation.

4.4 Methodology

4.4.1 Research Design

This research was exploratory in nature. Since little is known about the decision-making of property managers within the commercial real estate sector, a qualitative approach was selected as an appropriate way to gain understanding and perspective from these and other key stakeholders about the motivations and barriers to engage in sustainable energy management practices (Creswell, 2009). This approach aligns with other researchers who have investigated energy management practices in commercial buildings in other jurisdictions (e.g., Elliott, Bull, & Mallaburn, 2014; Miller & Buys, 2008).

4.4.1.1 Targeted population

The objective was to interview senior decision-makers within three target populations (different actor groups within the principal-agent context): building owners/property managers, operations staff, and leadership amongst tenants within commercial office buildings or portfolios. In the context of a building as an energy system, each target population was perceived to offer unique experience and insight on how energy management considerations could impact their role within a commercial office building, and subsequently the overall energy performance.

Corporate Executive: As a proxy for the property owner, typically pension fund or REIT for Canadian commercial real estate, a corporate executive from the private-sector property management firm or public-sector institution was selected. The chosen individual would have direct contact with a representative of the ownership group, and would be knowledgeable about their motivations for investing in building retrofits and/or supporting stakeholder engagement strategies (e.g., corporate-wide sustainability training as a reason for selecting a property management firm to represent them).

Sustainability Director: At the corporate level, sustainability directors are responsible for developing sustainability strategy and corporate training, and writing sustainability reports. They act as a spokesperson for the property management firm or public-sector institution on sustainability issues, including responses to investor questionnaires. Another responsibility is applying for LEED/BOMA certification/re-certification. Sustainability Directors work with property managers on energy efficiency opportunities, based on data monitoring and measuring. Some firms have portfolio-level sustainability directors for showcase buildings.

Property Manager: Responsible for day-to-day operations for a building or building portfolio, including operationalizing corporate strategy. Duties include supervision of staff, including training, regulatory compliance and monitoring/ measuring resource consumption (energy, water, waste), and tenant relations. Property managers analyze and track spending according to an annual budget, and look for efficiency opportunities. A priority is maintaining building-level revenue, so property managers will work with leasing agents to attract new tenants and supervise building upgrades, as needed.

Operator: Responsible for building operations, including management of building automation systems mechanical maintenance, repair and replacement of equipment. Typically work in accordance with a preventative maintenance protocol (PMP) and standard operating procedures (SOP). Training and apprenticeships for skills trades may be part of duties, along with sustainability training, if mandated by the property management firm.

Tenant: In terms of building occupancy, the leadership representative communicates with the property manager about any issues with the rented space. Depending on the lease structure, tenants are typically responsible for participating in the source separation of their waste, and pay the electricity bills for their space through an operating fee which is calculated based on square footage, unless metered units are provided.

4.4.2 Primary Data Collection

4.4.2.1 Population Sample

A formal research partnership was established with the Building Owners and Managers Association (BOMA) of Canada, which provides a range of services to the nation's commercial real estate industry. BOMA Canada's membership includes over 3200 building owners, managers, developers, facilities managers, asset managers, leasing agents, brokers, and product and service providers (BOMA Canada, 2016). An informal research partnership was also established with the Industrial-Commercial-Institutional (ICI) working group of Climate Action Waterloo Region (WR), a collaboration of organizations and community members focused on climate change adaption in Cambridge, Kitchener, Waterloo, and surrounding townships. Convenience and snowball sampling techniques were used to identify potential interviewees from private-sector property management firms and public-sector institutions such as municipalities, institutions of higher education, and school boards. A convenience sample of 17 building portfolios (owned/managed by BOMA Canada's members) was made, along with a sample of 8 ICI organizations from Climate Action WR's membership. Out of 29 identified building portfolios, 24 participated in the study (response rate of 83% at this level). The industry partners were asked to consider the following characteristics in the sampling of portfolios: building size, age, location, level of green performance certification[25]. For each portfolio or organization, the respective owners/managers were invited to participate in the interviews, via an executive member of BOMA Canada or the ICI working group chair of ClimateActionWR. Once these individuals had participated in the research, they were asked to identify operators within their organization, and tenants within their building portfolio that may be interested in participating in the research. In total, 43 interviews were conducted with corporate executives, sustainability directors, property managers, operators, and tenants in senior decision-making positions (out of 47 invited participants, for a response rate of 91%). Interviews ranged from 30 to 115 minutes, with most interviews being approximately 60 minutes in duration. Interviews

[25] It is recognized that due to the nature of BOMA Canada and Climate Action Waterloo Region's membership, the building portfolios in the population sample may be skewed towards organizations that embrace sustainability as a strategic principle. That said, many of the property management firms that participated in the study manage a portfolio of assets.

were all electronically recorded (audio only). During interviews, handwritten notes were made on emphasized content, and to record personal observations (participant's perceived level of interest in the discussion). Interviews were transcribed verbatim. The characteristics of the sample population are illustrated in Figure 21, and detailed in Table 11.

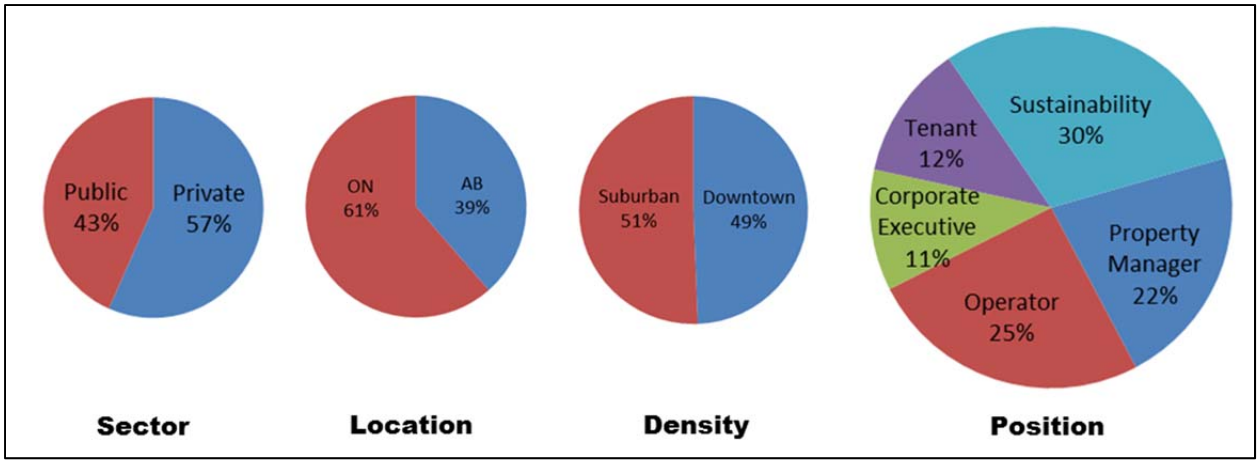

Figure 21: Sample population characteristics (n=43 participants)

Table 11: List of interviewees

No.	Sector	Position	Location	Density	Building/ Portfolio No.
1	Public	Operator	ON	Suburban	15
2	Public	Sustainability	ON	Suburban	16
3	Public	Sustainability	ON	Suburban	17
4	Public	Sustainability	ON	Suburban	18
5	Public	Operator	ON	Suburban	19
6	Public	Operator	ON	Suburban	20
7	Public	Sustainability	ON	Suburban	20
8	Public	Operator	ON	Suburban	21
9	Private	Sustainability	ON	Downtown	1
10	Private	Property Manager	ON	Suburban	2
11	Private	Corporate Executive	ON	Suburban	2
12	Private	Property Manager	ON	Suburban	2
13	Private	Sustainability	ON	Downtown	2
14	Private	Property Manager	ON	Downtown	2
15	Private	Sustainability	ON	Downtown	3
16	Private	Property Manager	ON	Suburban	3
17	Private	Corporate Executive	ON	Downtown	4
18	Private	Sustainability	ON	Downtown	5
19	Private	Sustainability	ON	Downtown	6
20	Private	Sustainability	ON	Downtown	7
21	Private	Sustainability	ON	Downtown	8
22	Private	Property Manager	ON	Suburban	9
23	Private	Tenant	ON	Suburban	9
24	Private	Tenant	ON	Suburban	9
25	Public	Operator	AB	Suburban	22
26	Public	Operator	AB	Suburban	23
27	Public	Tenant	AB	Downtown	23
28	Public	Sustainability	AB	Downtown	23
29	Public	Operator	AB	Suburban	23
30	Public	Tenant	AB	Suburban	23

No.	Sector	Position	Location	Density	Building/ Portfolio No.
31	Public	Operator	AB	Downtown	23
32	Public	Property Manager	AB	Downtown	23
33	Public	Property Manager	AB	Downtown	23
34	Public	Operator	AB	Downtown	23
35	Public	Operator	AB	Suburban	23
36	Public	Property Manager	AB	Downtown	24
37	Private	Operator	AB	Downtown	10
38	Private	Corporate Executive	AB	Downtown	11
39	Private	Property Manager	AB	Downtown	12
40	Private	Corporate Executive	AB	Downtown	12
41	Private	Property Manager	ON	Downtown	2
42	Private	Tenant	ON	Suburban	13
43	Private	Tenant	ON	Suburban	14

4.4.2.2 Interview Protocol

An interview protocol was developed based on Maxwell's (1996) interactive approach/model to qualitative research design. The prepared questions were neutrally worded, and focused on the participants' roles and responsibilities within their organizations, and their decision-making criteria with respect to considering energy management (and sustainability, more broadly) initiatives within their role, and their motivations and barriers for engaging in these initiatives. The prepared questions were validated for relevancy and completeness by BOMA Canada. The interviews were semi-structured, enabling participants to describe their experiences and rationale for decision-making within their roles in their own terms. The focus on individual decision-making and motivations and barriers for engagement is directly linked to the overall research aim of identifying leverage points for changing the behaviour of actors within commercial buildings as systems. This type of exploratory research design allows for individualized conceptions and rich details to emerge. Example interview questions and themes are presented in Table 12, and the interview protocol is presented in Appendix F.

Table 12: Sample interview questions categorized into themes of behavioural influences

Theme	Sample interview question and prompts
Built Environment (Physical components or Infrastructure)	QUESTION: In the last five years, have you made any investments or implemented specific activities that have the potential to reduce the environmental impact of your assets? If so, what motivated those investments? PROMPTS: Utilized regional/provincial/federal incentives (roving energy manager)
Leadership Context (Human Components, Individual Actors / Social Institutions)	QUESTION: In regard to the different aspects your roles and responsibilities (previously described), what are the key decision-making criteria? PROMPTS: Corporate Social Responsibility - corporate mission, values, social license
Stakeholder Engagement (Individual Actors)	QUESTION: Do you think there is a role for building managers in promoting a culture of sustainability in the buildings they manage? If so, what would that role be? PROMPTS: A culture of sustainability is characterized by shared values, norms, language,

	and practices focused on making individual and societal choices that foster social, economic and environmental sustainability.
External Drivers (Social Institutions)	QUESTION: In regard to the different aspects your roles and responsibilities (previously described), what are the key decision-making criteria? PROMPTS: Regulations - Compliance with mandatory or voluntary standards, industry best practices

4.4.2.3 Ethics

All interviews (and recruitment of interviewees) were conducted with the approval of, and in accordance with, the University of Waterloo and the Wilfrid Laurier University Offices of Research Ethics (ORE#21928 and REB#4896, respectively). Samples of the recruitment materials are presented in Appendix G.

The most important ethical issues regarding this project was the recruitment of participants and maintaining the confidentiality of the data provided. In order to achieve the research objectives, it was necessary to have access to a range of stakeholders within the commercial real estate sector. BOMA Canada and two of its regional branches, along with Climate Action WR, facilitated introductions to their members and broader network, and interview participants were drawn from this group. All potential interviewees were above the age of 18, and working professionals within the identified sector (i.e., they were not members of a vulnerable population). Participants in this research did so voluntarily and without coercion. The process by which potential interviewees were communicated with and invited to participate in the study was developed in accordance with the guidelines of UW and WLU ethics policies. A brief description of the process is provided here, and full copies of the ethics applications, along with statements of approval, from both universities are available upon request.

The invitation process consisted of the following steps:

1. BOMA Canada, Toronto, and Edmonton executive members (or a ClimateActionWR Committee member) identified individuals that would be valuable participants in this research;
2. The aforementioned individual sent an initial email to the identified contact, describing the study, including the benefits to the industry sector, and asking if the person would agree to be contacted by a researcher to learn more. This email was scripted, and indicated that BOMA (or ClimateAction WR) would not be informed about their decision to participate, and that participation was completely voluntary, with no impact on their membership.
3. If the individual agreed, Prof. Manuel Riemer (Principal Investigator) or Ms. Stephanie Whitney (doctoral candidate) contacted them and provided them with a 1-page project brief, and the short PowerPoint presentation that was given to BOMA Canada's Board of Directors in November 2016. In the same email, we invited them to participate in the study, and also provided highlights from the Informed consent letter regarding the anonymity of their participation and ability to withdraw their consent at any time.

4. If the individual agreed to be interviewed, a date was scheduled, and the interview questions, along with the informed consent letter, were attached to the meeting invitation.
5. At the beginning of every interview, 5 to 10 minutes were spent going over the details of the informed consent letter – context of the study, how data would be aggregated and used, procedure should quotes be desired, location and length of data storage, etc. – to ensure that participants understood what they were signing.

The information collected and analyzed was anonymized such that all individual and organization names were removed. Participants and building portfolios were assigned identification numbers, which were then linked to sample characteristics (sector, location, position, and density).

4.4.3 Data Analysis

An inductive approach to data analysis was used, allowing meaning to be constructed by the interview participants (Creswell, 2009). The transcripts generated from the 43 interviews were interpreted using 'open' and 'axial' coding, conducted in Dedoose (version 8.0.36), a web-based software application for qualitative and quantitative data management and analysis. Open coding was used to apply conceptual labels or codes to the data, based on the participants' own words (Robson, 2002). Axial coding was then used to categorize the open codes, and the data were further explored for relationships between the categories, including themes and patterns (Robson, 2002). After one round of open and axial coding, the resulting codebook was compared to the deductive conceptual framework that was presented in Section 2.4. It was determined that the two levels of codes fit well within the four themes that were conceptualized[26], and thus the themes could be used as the first-level codes. An excerpt of the coding conducted in Dedoose can be found in Appendix H.

The findings from the literature review were used to validate the final codes, which were determined inductively. In this mixed methods approach, the intent was not to be bound by definitions and terms that emerged from the deductive findings, rather to compare and contrast the findings from the literature with the meaning of terms, as perceived and experienced by the study participants (Creswell, 2009). While the conceptual framework was developed based on the literature review, prior to the data collection pre-coding, to the extent possible, conceptual bias was mitigated in the development of the open and axial codes through the use of in-vivo coding to allow the meaning to emerge from the participants' interpretations. There was a high degree of alignment between the terms grounded in the literature and the language used by the study participants. As such, the resulting codes from this mixed methods approach reflect both the accepted language used in the research literature and the voices of the study participants.

[26] The literature on behaviour within organizations and commercial buildings was found to utilize terminology that was presented in the interviews. Given the applied and practical nature of the research topic, and the level of awareness of energy management and sustainability within the commercial real estate sector, there was a high degree of congruency between the deductive conceptual framework and inductive codes.

4.4.3.1 Qualitative Codebook

A qualitative codebook was developed for this study, as is best practice in data analysis for qualitative research (Creswell, 2009). This codebook was refined and validated with the assistance of two researchers involved in a broader research project related to this study. After the first round of coding was completed, the codebook was shared with the principal investigator, who reviewed definitions and examples of excerpts selected to represent the codes. The general ideas that participants shared, along with the perceived tone of these ideas, as captured in field memos during data collection were also discussed. Following revision of the codebook and recoding of the data, this process was repeated with a doctoral candidate involved in the project. After a third round of revision and recoding, a blind coding test was conducted with the same doctoral candidate in order to validate the codebook. Three interviews were recoded separately by Ms. Whitney, and any discrepancies in codes assigned were discussed until consensus was reached. The revised codebook was once again shared with the principal investigator, along with the cumulative code count as generated by the Dedoose web-application. The qualitative codebook and cumulative code count are presented in Appendices I and J, respectively.

4.4.3.2 Coding Results: Overview

The analysis revealed 52 unique codes, including the four themes identified from the literature review, which were coded as parent codes, alongside the codes motivations and barriers. A compilation of the highest-ranked codes (cumulative count), including co-occurrences with the codes motivations and barriers, and the code presence (i.e., number of participants that used the code) is presented in Appendix K).

By focusing on the highest-ranked codes, the potential exists for disproportionate bias towards meaning or ideas that were significant for a sub-set of the study participants, but may not accurately represent the spectrum of perspectives of the sample population as a whole. In order to address this limitation of quantitative analysis of the qualitative data, the number of participants that used a code has been reported, and the interpretation of the codes draws from quotations from different participants, to increase transparency and trustworthiness of the findings. The quotations presented in the Results section were chosen from excerpts containing the highest-ranked codes as examples that served to illuminate the overall sub-theme being discussed.

4.5 Results

A large portion of the semi-structured interview protocol was aimed at characterizing the energy management decision-making process presented in Figure 16. The open-ended questions allowed for comparison of the decision process between the different stakeholders and contexts. Figure 22 illustrates the total number of mentions by each stakeholder group throughout the interview, categorized by major theme.

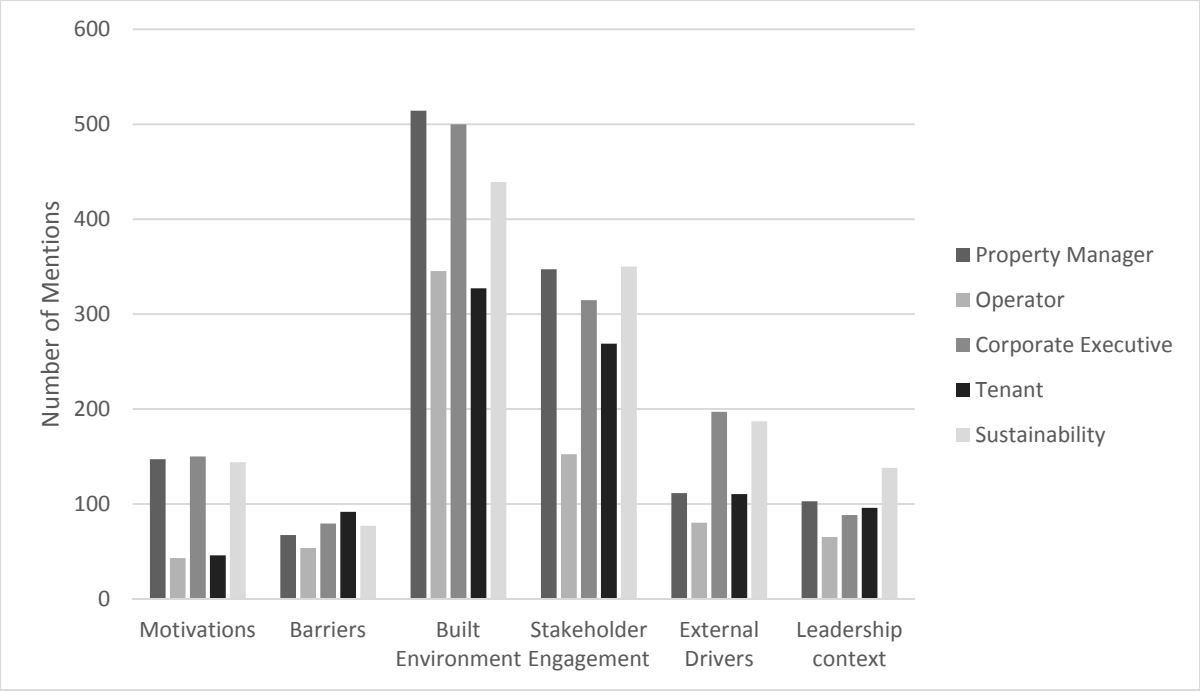

Figure 22: Comparison of number of mentions per major theme of energy management decision-making: (1) Motivations, (2) Barriers, (3) Built Environment, (4) Stakeholder Engagement, (5) External Drivers, and (4) Leadership Context.

One goal of this research was to use a systems view to investigate the energy management of commercial buildings by exploring the decision-making of individuals while recognizing their nested positions in various organizational and external contexts. As such, a conceptual overview of the relationships between key decision-makers and a commercial building is presented in Figure 23. This overview was derived from the interview data, using interviewees' descriptions of their major roles and responsibilities and decision-making processes, and reflects the four broad themes of influences on energy management decision-making that emerged from the literature review. The commercial building (built environment) is represented at the bottom of Figure 23, along with the GHG footprint (environmental impact) associated with building operations and use. The stakeholder groups (leadership context) and sub-actors within each group (stakeholder engagement) are identified in the middle of the figure, along with their respective sub-goals as they relate to the commercial building. The exogenous factors (external drivers) that influence each stakeholder group's objectives for the building and decision-making processes are represented at the top of the figure. Finally, arrows have been used to delineate communication among the stakeholder groups and sub-actors. Specific components will be elaborated upon in the following sub-sections.

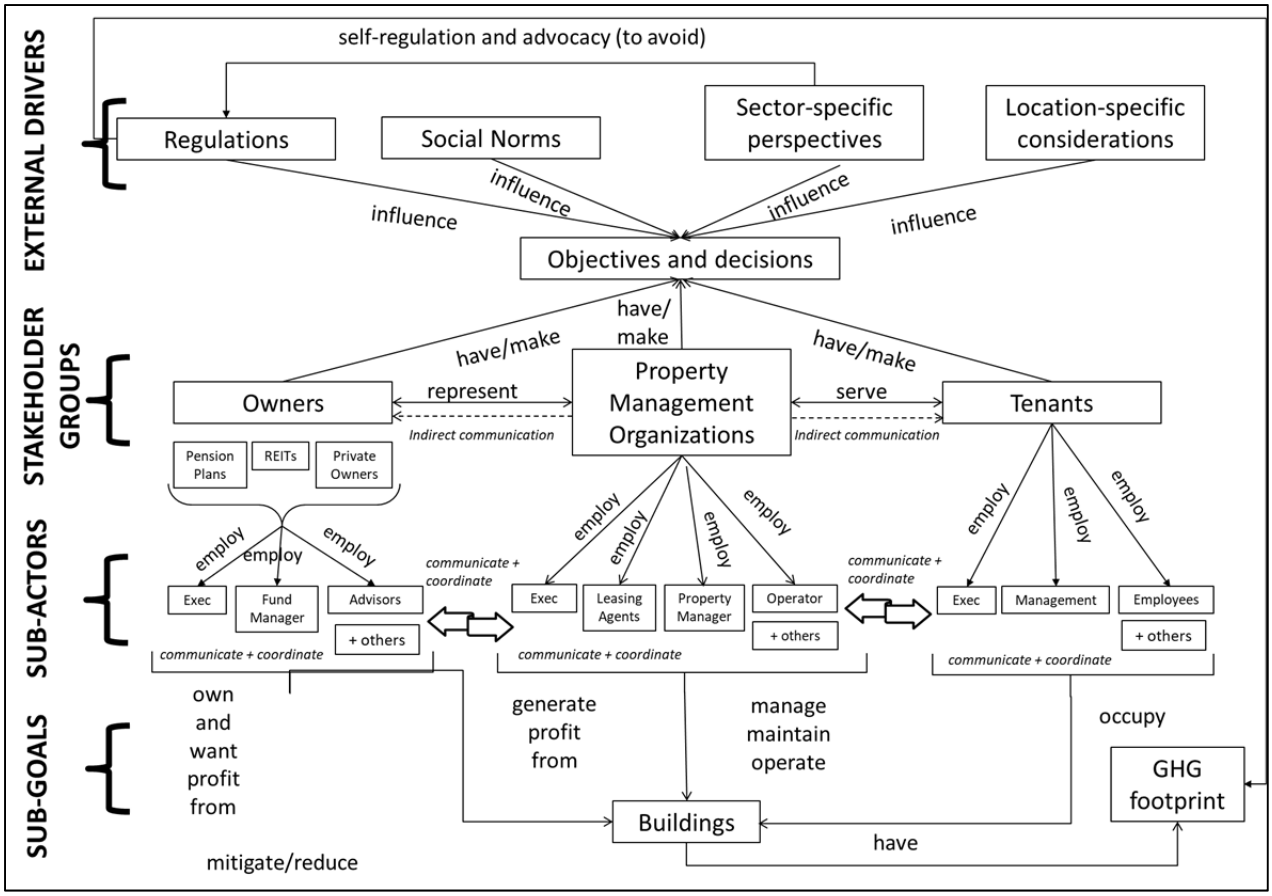

Figure 23: Conceptual overview of the relationship between a commercial building's stakeholders

An important premise of system theory is that the behaviour of a system is a function of the structure and interconnections between the physical and living components (Meadows, 2008). As such, the study findings are structured under three main headings:

1. System structure: Elements, actors, and influences

2. System goals and sub-goals; and

3. System dynamics and patterns of behaviour.

4.5.1 System structure: Elements, actors, and influences

In this subsection, the system levels, niches, organizations and actors will be described in the context of the four major themes from the literature.

4.5.1.1 Built Environment

The Built Environment theme received the most mentions, with 38% of the coded text categorized under this theme. The physical boundary of a commercial building was chosen as the system boundary for this study, as the site where energy is managed and used, even if not all actors are

located within the space. To ensure the continued function of a building, stakeholders described using regular assessment procedures to inform and budget for planned maintenance:

> "A lot of our focus actually needs to be on these measures…completing technical building assessments systematically - it's making sure we take those recommendations into our annual planning process". (S15)[27]

4.5.1.2 Stakeholder Engagement

The Stakeholder Engagement theme received the second highest number of mentions, with 25% of the coded text categorized under this theme. This theme included internal and external communication with multiple purposes and targets (sustainability reporting, staff training, tenant and customer outreach, etc.), and both formal and informal processes of engagement. Relationships between stakeholders were described in degrees of separation from direct contact with representatives within one's own organization (e.g., property manager with operator, or with corporate executives), to indirect contact through one or more individuals from different organizations (e.g., building owner to tenant). Generally, relationships between stakeholders facilitated knowledge exchange or dissemination in pursuit of individual and/or shared goals:

> "If BOMA has some kind of seminar that would be useful to my staff, I always allow and tell them to attend…what I say and what somebody else says, sometimes it sounds different. Or they see a different point and … it makes sense. So, I think education is the key to understanding what everybody is trying to achieve." (PM36)

Especially for property management firms, stakeholder engagement involved keeping abreast of industry norms including innovation, best practices and the activities of peers and competitors in the market:

> "We would look and see, what's everyone else doing, and at a bare minimum, we're going to be doing that." (PM41)

> "We're always monitoring what other facilities are doing across Canada, looking at best practices and new facilities that are being designed, and what's unique and different in them so that we can learn and bring that back with us within our facilities" (O31)

4.5.1.3 External Drivers

The External Drivers theme contained 12% of the coded text. This theme included regulatory instruments such as climate policy, financial incentives, and voluntary initiatives as a response to market signals. The industry's desire to self-regulate (avoiding command and control regulation to mitigate GHG emissions) emerged from the interviews:

[27] Participants have been quoted using their position (CE = Corporate Executive, PM = Property Manager, O = Operator, S = Sustainability Director, T = Tenant) and participant number.

> "People were using the Energy Star portfolio manager, but it was in U.S. metrics and weather normalized to the U.S., and there was pressure from the industry to say you know we're using this. Can Environment Canada do something about this? Nobody wants to be regulated, nobody wants to be told what to do." (S13)

Financial incentives, offered by the Federal or Provincial government, helped create the business case for retrofit investments by reducing the capital cost and shortening the payback period. This was particularly true for lighting, but less so for larger building envelope items (insulation, solar rooftop installations, windows, etc.), and heating, ventilation and air-conditioning (HVAC) systems:

> "Lighting is something where I think we certainly do replacements prior to the end of the useful life, because there has been over the last number of years there's been a lot of benefit to doing so, where there's energy savings and therefore cost savings. There's been good incentive programs through the OPA and local distribution companies and so on." (PM10)

The interviews revealed that the business case to retrofit older buildings could be more difficult to justify to building owners. Often times HVAC systems and other capital-intensive retrofits are needed to have any material impact on the energy savings for older, less efficient buildings, and the incentives currently offered do not reflect the significant upfront investment:

> "Buildings that are a little bit older… we had fans or chillers that were old that there are some rebates, but the cost, the capital cost is high. And that may be a barrier. The rebate is tiny by the capital cost is… the great expression low hanging fruit. Those lights are always a simple one." (PM22)

4.5.1.4 Leadership Context

The Leadership Context theme included 9% of the coded text. This theme included corporate strategy, including measuring, monitoring, reporting of key performance indicators (KPI) and targets, and organizational structure. The extent to which organizations embraced corporate social responsibility (CSR) as part of their mission, vision and values influenced the energy management and overall approach to operating a commercial building:

> "Canadian real estate is mostly owned by pension funds…the owner of this building, they are part of the UN responsible property investment group. They have made commitments on their climate footprint. They see both risk and reward… you can have physical risk to your property and reputational risk if you're not there." (S13)

In the public-sector, the activities of municipalities and institutions were also prioritized in terms of corporate strategy, as expressed by the mission, vision, and values of the elected leaders of government:

> "Everything we do is based on the strategy. When you go to Council with an ask, when you go to do something with a report, you need to quote it…how does this meet the City's goals? One of our big goals is environmental sustainability". (PM32)

This description of system structure provides insight into the latent behaviours of the system to achieve the system goals and sub-goals.

4.5.2 System goals and sub-goals

From the system perspective, individual behaviour may appear to be irrational and even in opposition to the desired outcome, yet from each actor's narrow view within the system boundaries (based on the limited information available to them), individuals act reasonably (Meadows, 2009). System changes thus require restructuring of goals, information flows, incentives and disincentives so that "separate, bounded, rational actions do add up to results that everyone desires" (Meadows, 2009, p. 108). As a first step to decreasing the performance gap in commercial buildings, it is necessary to understand the sub-goals of the system actors.

4.5.2.1 Profit generation or provision of service

Profit generation and efficient provision of service were the main objectives for building owners[28] and property managers in the private- and public-sector, respectively. Profit was simplistically described as being a function of the value of a building's long-term leases, including the occupancy rate and rent charged. The terms asset value, identity, and competitive advantage were used to describe how profit is derived from the ownership and management of a high-performance or 'green' building. Corporate executives, property managers, and sustainability professionals discussed sustainability as being integral to an organization's marketed identity or value proposition of their business, as well as their corporate strategy more frequently than operators or tenants. This was predominantly in the private sector and downtown core, but also in prime suburban real estate markets and municipalities or public-sector institutions experiencing economic growth. These three groups of stakeholders consistently spoke of identity or corporate image as embodying the values (excellence, leadership, environmental stewardship, etc.) of the building's owner(s):

> "Some owners are very, we'll say, easy to work with in the sense of with money, with their capital. They want their buildings to be assets that reflect them and they are not afraid to spend money to do the right thing. We always want to have an owner like that." (PM22)

In many cases, an organization's identity was described in terms of the evaluation criteria used to determine an office building's classification[29]. The ability of a property to generate profit was

[28] In this study, building owners in the private-sector were represented by corporate executives from property management firms. These individuals have direct contact with representatives of the building owner.

[29] An office building's classification is relative to the other buildings in a given market (e.g., downtown Toronto). Class A buildings are the most prestigious buildings (most attractive, built with the highest quality materials and construction methods) with the most amenities in the best locations. Class B and C are based on the definition of Class A, with respectively less desirable characteristics at each level (BOMA Quebec and BOMA Canada, n.d.)

directly linked to the prestige and pride associated with managing or occupying a Triple-A asset. Most participants agreed that building-level environmental certification and formal sustainability management practices (criteria for Class A designation) were important components of their organization's identity or value proposition that led to greater profit and competitive advantage. Executives, property managers, and sustainability professionals frequently discussed maintaining and/or re-applying for environmental certifications as a large part of their annual budgetary planning, strongly influencing their management decisions for commercial buildings. The necessity for the environmental certification of buildings in order to attract and retain tenants was directly connected to the competitiveness of the real estate market, and what tenants demand for their rented office space:

> "In most cases you need to target, certainly in an urban office context, LEED Gold or better. That's where the market is…if you want the high quality tenants, it's a box they're looking to check. It's a new definition of quality." (S15)

The demand for environmental certification, and its use for signaling the value of occupying a green building, was not limited to the private-sector. The reputational value of certified office buildings was also discussed by participants in the public-sector, as many municipalities and other publically-funded institutions are incorporating sustainability into their long-term strategic planning:

> "All these buildings tried to get the City to move in, and 90% of them didn't even make it past the first round because they couldn't offer the green, they couldn't offer the LEED, and all those things. Nobody wants to be in a former A-class building that's now being degraded." (PM32)

Corporate strategy, competitive advantage, and asset value were the 2nd, 4th, and 6th highest-ranked codes co-occurring[30] with motivations, respectively. While the identity code was not in the top 10 overall code counts or top five co-occurrences with motivations, it did co-occur (minimum twice, maximum 10 times) with each of the top five motivations, and was a common motivator across all stakeholder groups. The interviews illustrated that sustainability values are embedded in the profit generation process of private-sector owners and property managers associated with Class A buildings and portfolios of buildings. Similarly, green buildings are integral to the provision of service in the public-sector. Sometimes these values are easily converted into retrofit investments (in order to maintain or improve the building classification or level of environmental certification), but this is subject to budgetary constraints. The interviewees repeatedly used terms such as Triple-A, Class A, quality, pride of place, and reputation, and these terms carried significant meaning for them.

4.5.2.2 Efficient operation and maintenance of the building infrastructure

The main objective of operators was to operate and maintain the building infrastructure as efficiently and effectively as possible. In the private-sector, this maximized the profits generated from owning and managing the building, through cost savings. In the public-sector, efficient building operation

[30] The Dedoose software allowed for multiple codes to be assigned to each excerpt. If applicable, excerpts were coded as motivations or barriers, as well as the sub-code (e.g., tenant expectations).

was perceived as being prudent with taxpayers' dollars. In both sectors, effective building operation was linked to keeping tenants comfortable and content, and doing so as efficiently as possible was prioritized.

> "Most of our existing infrastructure and assets, we would take a look at through preventative maintenance alone, trying to make them as efficient as possible. And so one of the things that we do now is programming as the emphasis on the operational life cycle of the infrastructure and then education and awareness… so education and information management." (O35)

For some stakeholders, organizational processes and routines strongly influenced their energy management from the beginning (i.e., whether retrofit investments were made), while in some instances they determined the extent to which new equipment was optimally operated. The primary system barriers to energy management were securing staff buy-in and ensuring capacity within the property management organization to trouble-shoot high-efficiency (HE) technology. Operators were the most vocal against HE technology (45% of the mentions were from this stakeholder group), citing the sensitivity of the equipment or frequent incompatibility with older, existing building systems, and increased installation and maintenance requirements and costs:

> "The original boilers are approximately 80% (efficient)…and it's very simple, user friendly. Some of the new units are so finicky that something goes wrong…a flame rod gets dirty and all of the sudden it doesn't work, the whole system goes down … they can't use the original flues. They have actually put in new piping. So the cost for the fixture, the unit itself is a little bit more, but the installation is a lot more." (O37)

Some operators also perceived the overall design of HE technology to be flawed. While it was recognized that installing these systems was required to meet environmental certification requirements, some operators expressed concerns regarding the lack of consideration, at the building design stage, for the additional maintenance work required to operate the equipment:

> "The design that we're seeing with the photovoltaic, the grey water systems, the condensing boilers, the design often isn't good… sometimes they just don't work, period. And we're faced with the issue of making them work…we're seeing in some cases they are under-designed, so we need to deal with that… so there's a higher requirement for maintenance and there's a higher failure rate to these systems." (O26)

The challenges with operating HE technologies were acknowledged by other stakeholder groups, but were perceived as human resource issues rather than flaws with the design of the technology itself. At the executive level, the issue was related to capacity-building and ensuring that staff possess the requisite skills to interpret the feedback from the complex energy management systems that often accompany HE technology:

> "You can't just do the upgrades...once we did all the upgrades, we had to do a lot of training and then we had to instill the best practices for our teams for our tenants, for our vendors. So it became part of the normalcy for them." (CE17)

There was general acceptance from corporate executives, sustainability directors, and property managers that operators (who are tasked with the optimization of energy consumption with a building envelope) need sufficient training so that they can effectively troubleshoot and achieve continuous performance improvements. Another human resource challenge that was discussed by interviewees was employee turnover. The commercial real estate sector was described as a dynamic industry with many career opportunities for talented individuals. Turnover was seen as a barrier to organizational capacity-building and operation of HE technology, and also the acceptance of behavioural programs by tenants.

> "What we found is that the facility maintenance team wasn't necessarily comfortable with the new technology that was installed, or if they were, it was specifically one or two individuals. And then if you have a turnover you're kind of losing that." (T29)

4.5.2.3 Tenant expectations

Tenants described their organization's core business function, and their occupancy of a green building as supporting component of that function.

> "The companies that we bought, all these brands, they … were very much environmentally focused, social responsibilities, sustainability… not just in the products they have, but the cultures that they live/enjoy/share with their customers. So it's something that we've adopted and adapted to as well... we also live it in our office, in our staff, and in our corporate image… it's important for how I retain and recruit staff…but also looking at my customers. It's not just one side or segment of the population." (CE42)

Tenants also perceived property managers as having a supporting role in their sustainability initiatives, with potential to positively or negatively impact the outcomes.

> "I think they have a role in supporting what their tenants want to do…building managers can either aid or hinder in any sort of sustainability program being developed, big time. Like if our building manager said, you can't have your EV charging, even though we pay for it. It's in their parking garage, on their land they control. If they said you have to stop, we would have no means to say anything". (T23)

Most participants from property management firms spoke proudly about offering sustainability services as a core component of their overall tenant relationship program (another criteria of Class A designation), and one of many services that professional and experienced property managers provide. The quality of the tenant relationship programs offered by various property management firms was perceived as a distinguishing characteristic to attract both building owners and tenants:

> "One of the reasons why they are with us as the institutional owner, is because of what we do, because of the programs we have and because of our standing." (PM12)

> "That's really why I was hired-as a triple-A asset, this building houses tenants who require quality, of not just the day to day property management services, but as part of it - how we deliver sustainability." (S13)

It was also recognized that operational routines are driven, at least to some extent, by tenant demands, as their experiences and satisfaction with the building conditions factor heavily into the decision-making and operating practices of property managers and operators. At times, these decisions were at odds with standard operating practices to optimize energy efficiency:

> "This building also has a high (air) changeover, like 20 percent…the tenants, they prefer to have a large change-over of air, that's what we've always done. But for energy, we pay more money for that." (O37)

Corporate executives, property managers, and sustainability professionals generally perceived educating their tenants and creating awareness about energy management issues within the building as part of their tenant relations program (recall this criteria for Class A buildings), and as an opportunity to connect and nurture relationships with them:

> "If you are able to provide personalized, customized information to tenants, you win them over. In buildings where we have sub-metering and even buildings where tenants are billed directly on their consumption, we have greater engagement because they know for their suite or at least the floor what's happening…we get attention…it's benchmarking." (S18)

4.5.3 System dynamics and patterns of behaviour

In a system, "events accumulate into dynamic patterns of behaviour" (Meadows, 2009, p. 88). Long-term analysis of system behaviour over time illuminates the system structure, and is key to understanding why events are happening.

4.5.3.1 Interdependence and communication between actors

Within a commercial building, there is heavy reliance on information from other stakeholders to achieve the system sub-goals, described in Section 5.2. Building owners hire property management firms to represent them, and rely on their sector-specific expertise to generate profit from their capital investment. Property managers rely on building owners for initial and on-going capital investment, and on operators for their capacity with equipment.

In terms of information flows and coordination within the system (see Figure 23), a barrier that hindered the efficient operation and maintenance of the building infrastructure was lack of access to consumption output data, due to the building lease structure. When tenants pay their electricity bills directly to the utility, the property manager and building operators cannot access the consumption data to determine the actual energy savings from retrofit projects or adjustments to operational

procedures. The limited access to relevant data may result in behaviour that appears rational from an actor's perspective, but irrational from the systems perspective.

> "We've requested over and over again copies of the bills. They will NOT provide, for privacy and all that. But what we want to do is be able to track and see where we are so we can help them. We've done projects…installed LED lighting, and all the exterior lighting…it's huge. I don't know how much we've saved, because I can't see it!" (PM22)

Communication within and between stakeholder groups was described as having several key purposes with respect to energy management: capacity-building, creating awareness/education, sustainability reporting, public relations, and collaboration. With respect to internal communication within a property management firm, capacity-building and education of staff were strong motivators for developing engagement processes:

> "We wanted to get our real-time data in a format that we could use to drive performance improvement. We ended up recognizing that we needed to have a discussion and educate our teams on what a real-time energy target looks like. How do you interpret that data and how do you compare yourself to what your performance is, relative to what it should be? There was a deep dialogue about that. We went across the country and held workshops and people came and we ended up educating people." (S19)

The notion of what a building's performance 'should' be, reflects a shared objective at the actor-level for property management firms (see Figure 8) of operating a building as efficiently as possible in order to maximize cost savings and profit. Interviewees from property management firms acknowledged that involving decision-makers from other functions within their organization in key management processes would help optimize the performance and efficiency of building operations:

> "Our (internal engagement) process is under development. We realized from experiences that we didn't do a good job at it. So we're looking at the commissioning process to involve more of the operator, the facility maintenance team so that we do a better job of translating the intent of the design and the construction into how it operates on a daily basis." (O29)

The interviews with tenants revealed that property managers should not take for granted that their tenants relations program, no matter how comprehensive, is continually meeting the needs of all of their tenants. In at least once instance, a property manager of a multi-building portfolio outlined in great detail several engagement initiatives that their tenants reportedly valued, and used in their own marketing strategies with clients. Two tenants in one of the buildings were interviewed, and one had poor recall of most of the initiatives, while the other commented that they were unlikely to communicate any building-level initiatives with their clients, because they did not feel any ownership of the initiatives, whether energy related or otherwise:

> "(Our landlord) does lots of philanthropic stuff, and they invite their tenants to participate…. It's very hard for us to leverage that… if we're not mentioned as one of the contributors to that

program or initiative. Or if we have no way of measuring our contribution to it. So it just becomes a landlord thing, and it's of no use to us. I shouldn't say no use, because our employees certainly get a positive feeling from doing something good for the community. But as a company, it's very difficult for us to talk about that kind of stuff if we're not clearly identified as a partner in that initiative." (T42,)

Overall, achievement of the system goals and sub-goals (see Section 5.2) is dependent on many levels of human interaction with and decisions made about the physical infrastructure. In this study, it was recognized that the industry standard practice was to prioritize capital investment into the physical asset, often at the expense of investment in human capital needed to manage and operate the building:

"What happens is we have a tendency to invest a lot more in the building technologies and comparatively fewer dollars on developing the people. We're still trying to get over that idea of if you have the all the bells and whistles in a building, then the building will take care of itself…which is not the case." (S9)

4.5.3.2 Capital cost – a limiting factor

Despite the stature of Class A buildings, there was disparity in the translation of corporate image into investments in energy retrofits, primarily due to budgetary constraints at the portfolio-level. Spending on large retrofit investments (e.g., co-generation system or new boilers) was much more likely for flagship buildings in the downtown core:

"I used to manage a property in the suburbs which was an A-class property, but … there was a limited amount of money across a large portfolio. This building has that luxury of being a flagship for the portfolio- being shown as a showcase piece." (PM14)

As discussed in Section 5.1.3, financial incentives do reduce the capital cost and payback period associated with retrofit investments, but a substantial amount of capital is still required for HVAC systems and other large projects:

"You have to have the initial capital investment in order to get that incentive… we did some boilers earlier this year the cost was around $300,000. We got incentives of about $7,000." (CE17)

From the owner and property managers' perspectives, the laborious nature of the application process and the uncertainty of availability of financial incentives adds further risk to retrofit investments:

"The programs themselves, it can be sometimes very onerous…we did a large project…there was a certain lamp that was covered and the rebate was going to be given at the beginning of the program….post-audit, it was off….it's off the program, it changed while you were doing it. That's a barrier." (PM22)

Institutional barriers to access of data and information sharing were often discussed as artifacts of the structure of organizations, and the formal relationships between organizations, such as property management firm and tenant. Often times, the individuals that negotiate lease terms for a building are not the property manager and the tenant (occupant) of the building itself – for example, there may be leasing agents for both parties – yet depending on the conditions written in lease agreement, these individuals may need to be part of conversations regarding building operations. The complexity of organizational structures, confounded with leasing agreement specifications, led to ineffective and delayed decision-making at the building-level:

> "When you know we're trying to deal with very specific, very operational-like, we just want to have a conversation about your bins in your space, because we've noticed that you know in terms of waste management we're not doing great. I don't necessarily want to have a conversation with four people, so it's making it more and more complicated to have a simple conversation about bins. It's the nature of the work and I think it's interesting to understand the landscape of all of the people involved in the life of an existing building, because it's not just property managers and tenants. It's property managers, owners, and then tenants, occupants, and their representatives, and then we try to coexist and sometimes there is loss." (S18)

4.6 Discussion

Within the sample population of this study, it was generally agreed upon that the system-level goal is to reduce the performance gap, and there is empirical evidence suggesting that increased investment in building retrofits in combination with increased stakeholder engagement in energy management behaviours would make great strides in reaching this goal. Each stakeholder would benefit from the achievement of this goal, yet there are three main challenges: 1) There needs to be collective understanding and commitment to the system goal, rather than prioritization of individual objectives; 2) No stakeholder alone has the capacity and/or resources to understand and address all of the building's infrastructure requirements; and 3) It is unclear who should lead the engagement process, as energy management behavioural programs are linked to each stakeholder group's objectives, and subject to their specific motivations and barriers. This study makes an important contribution to these challenges by analyzing the major modes of behaviour that lead to a reduction in the performance gap, and offers a qualitatively grounded framework for conceptualizing the reinforcing and balancing feedback loops that may lead to greater retrofit investments. This study provides insights into some potential leverage points for intervention, in order to facilitate these modes of behaviour that promote the desired outcomes.

The results suggest that there are five major modes of behaviour that can lead to increased retrofit investments in commercial buildings: 1) Regulated building improvements; 2) Voluntary building improvements; 3) Voluntary operational/Management improvements; 4) Leveraging competitive advantage; and 5) Mainstreaming green. These modes of behaviour are represented as causal feedback loops in Figure 24, and discussed in greater detail in the following subsections.

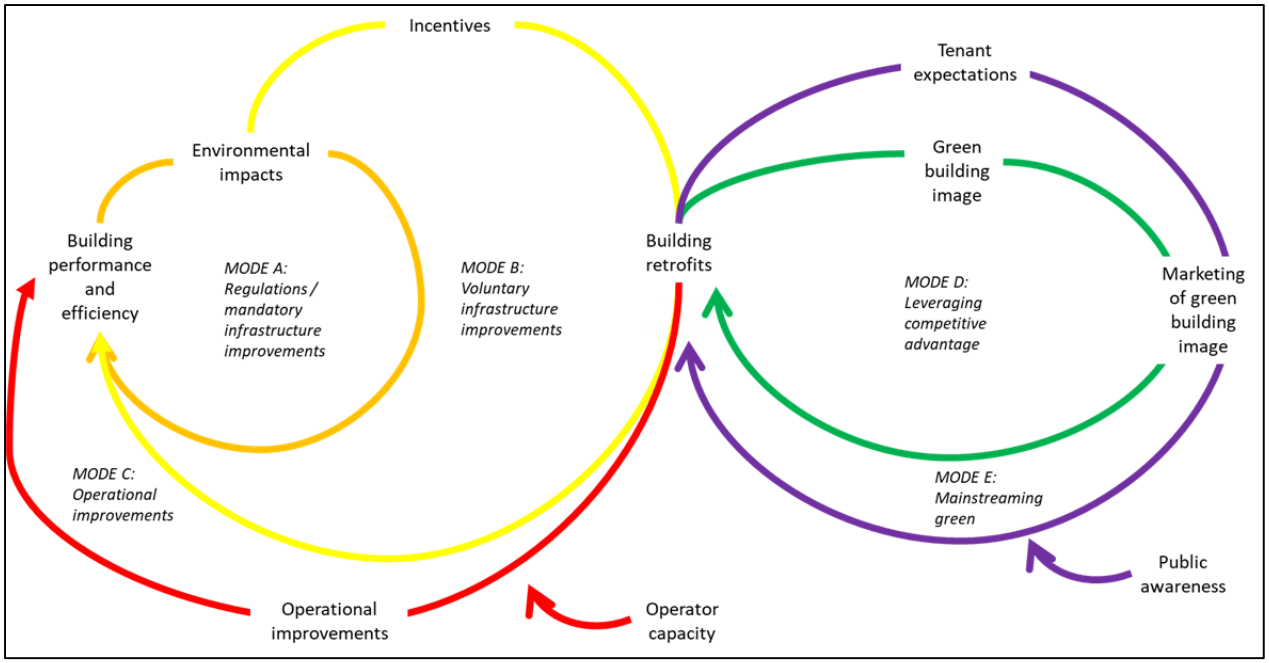

Figure 24: Modes of behaviour that lead to retrofit investments in commercial office buildings

4.6.1 Regulated infrastructure improvements

The regulatory landscape emerged from the interviews as a major external driver of energy management decision-making (recall Figure 23). Regulations were described as policy instruments used by all levels of government to mitigate the environmental impacts of buildings (see Mode A in Figure 24 and expanded in Figure 25). Mandated retrofits (e.g., more stringent building codes) were perceived as having the potential to increase asset management costs across the commercial real estate sector, without any non-performance benefits. There was recognition of policy instruments being applied within the Canadian landscape to mitigate climate change, and failure to 'get ahead' of mandated energy efficiency improvements was viewed as an operational risk. Indeed, the literature demonstrates that regulations at different scales are applied in order to curtail demand and improve the efficiency of new construction and existing buildings (Axon et al., 2012; Chiang Hsieh & Noonan, 2017; Elliott et al., 2014), and activities associated with regulatory compliance (e.g., performance testing, reporting, training) add incremental costs to building management. Interviewees described regulations at different scales – federal carbon tax, provincial building codes, municipal construction codes – as factors considered in their short- and long-term planning, and expressed preference for achieving building efficiency through alternative modes of behaviour, for reasons discussed in the sections, below.

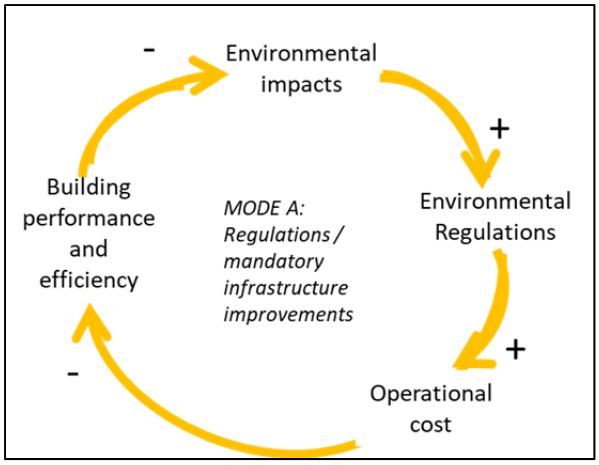

Figure 25: Mode A - Regulatory infrastructure improvements

4.6.2 Voluntary infrastructure improvements

Achieving building efficiency through voluntary infrastructure improvements (see Mode B in Figure 26) emerged as a preferred mode of behaviour to increased regulation, due to potential cost savings and flexibility associated with a voluntary and less prescriptive approach. The literature has demonstrated that retrofit measures can reduce energy costs by 30-40% (Dixon, 2014). Interviewees from private-sector property management firms described energy savings as translating to greater profits, the ability to keep rental rates at the same level, despite rising electricity prices, or having more equity available for capital improvements that can increase asset value. Financial incentives offered by the government further strengthened the business case for some types of retrofits (e.g., lighting) by reducing the initial capital cost and the payback period (see Fig 11 for expansion of the Mode B feedback loop). This was not the case for HVAC equipment such as boilers and chillers, where the incentives offered are typically less than 5% of the capital cost. While some lease structures allow for recovery of capital expenditures for building improvements to be passed on to the tenants through increased operating expenses to a limited extent (Martin & Gossett, 2013), large capital projects significantly reduce an asset's net operating income (i.e., increase operating costs), limiting these investments to portfolios with sufficient cash flow. The high cost of capital improvements represents a leverage point to increase building retrofits through a funding mechanism that does not affect organizations' operating income.

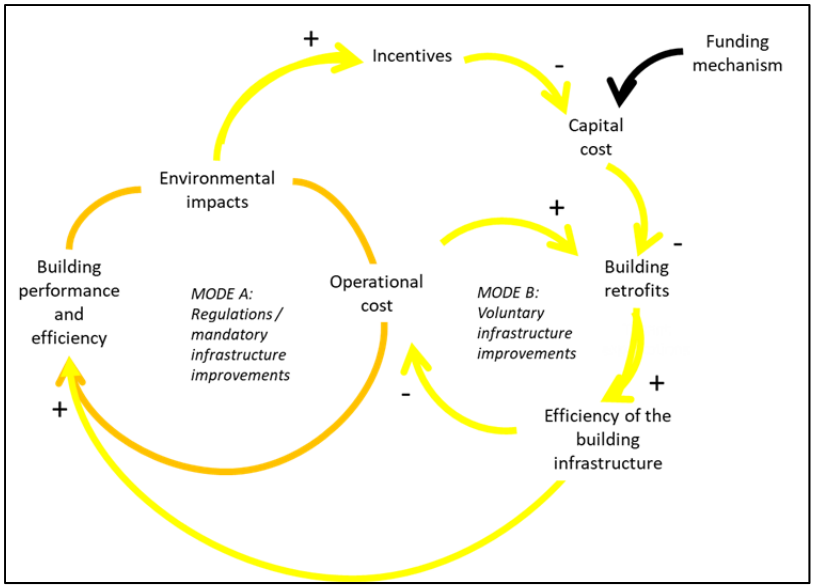

Figure 26: Mode B - Voluntary infrastructure improvements feedback loop

4.6.3 Operational improvements

Achieving building efficiency through improvements to operational efficiency emerged as another mode of behaviour that could lead to a reduction in the performance gap (see Mode C in Figure 24 and expanded in Figure 27). The interviews revealed that operational programming –training, embedding best practices into organizational routines, educating tenants and customers – is just as important, if not more important, than installing high-performance equipment and state-of-the-art energy management systems. Operators play a critical role in optimizing the performance of a building, and must have the capacity to fulfill that role. Another indirect benefit of increasing operator capacity (represented in Figure 27 as an intervention or leverage point) is the potential to increase buy-in and support from this stakeholder group for the purchase and installation of high-performance equipment as part of building retrofits. Increased training and inclusion of operators in the budget planning process both aid in reducing the misconceptions associated with green technology, and equips operators with the knowledge and tools needed to access and interpret feedback from energy management systems, empowering them to optimize building performance and efficiency.

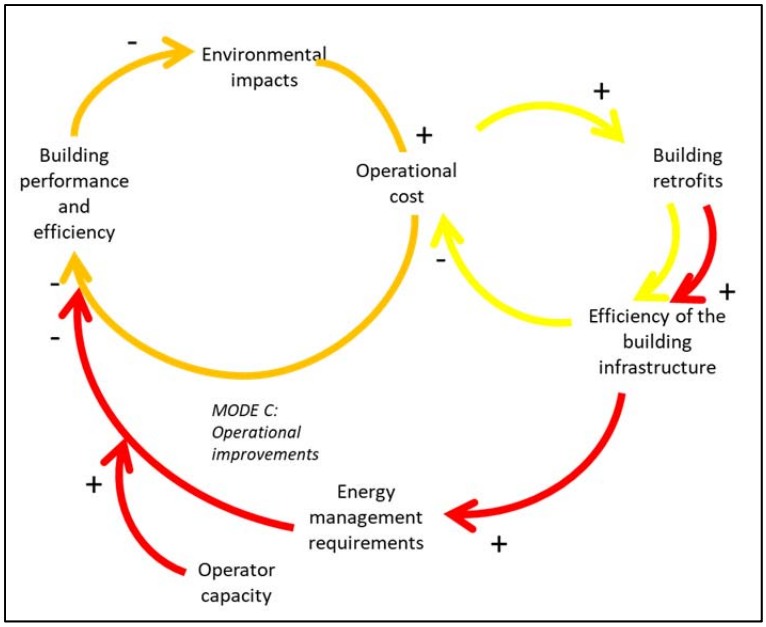

Figure 27: Mode C - Operational improvements feedback loop

4.6.4 Identity: Green corporate image

The interviews revealed that all stakeholder groups (irrespective of participant descriptor) were motivated by the green building image and their corporate identity or image, by association (see Mode D in Figure 24 and expanded in Figure 28). The comments made by stakeholders about the branding value of owning, managing, or occupying a certified green building, and the integration of sustainability into corporate identity validated Sørensen and Thomsen's (2006) proposed analytical framework that integrates three ideas: 1) objects can support identity construction, because of their signal value or because of their potential to provide a certain experience of self; 2) these meanings can reside in either a public or in a more private domain; and 3) these meanings can be vehicles for the maintenance as well as the acquisition of new life roles. There was general consensus amongst the interviewees in this study that green building image (signaled by a high BOMA or LEED score) was a benefit to be leveraged in one's market: for-profit property management firm seeking to rent office space, a municipality seeking to attract residents and businesses, or tenants displaying their CSR strategy. Mode D emerged as a reinforcing feedback loop through the marketing or communication of the building's green image and the integration of building's image into the corporate identity and CSR strategy of the organization, leading to more retrofit investments and further improvement of the building's green image (see Figure 28). Energy management was described as an integral component of organizations' corporate social responsibility (CSR), as demonstrated by corporate mission, vision, and values statements, and operationalized by key performance indicators (KPIs) and measuring and monitoring protocols. The extent to which private-sector property management firms and public-sector institutions and municipalities establish and maintain a reputation for leadership in CSR was perceived to translate directly into a competitive advantage in the respective marketplace. The consistent reference by interviewees to 'the market' highlighted a necessary condition of having a corporate image, namely being in the public eye.

Indeed, many interviewees explicitly referred to green-building certification as an operational efficiency tool, but also as 'a marketing tool' to attract and retain tenants.

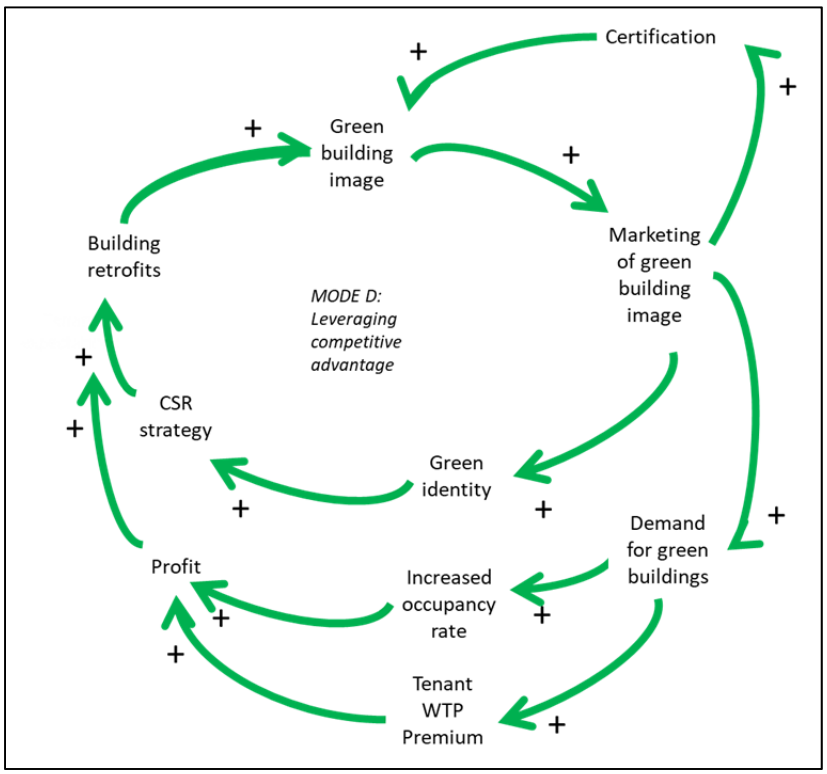

Figure 28: Mode D - Building green image feedback loop

The integration of energy efficiency into an organization's corporate image as seen in the Results (buildings as reflections of the owner, Section 5.2.1; sustainability as part of corporate culture to be shared with customers, Section 5.2.3) align with other studies about workplace behaviours, which have found that individual and organizational values can shape identity. For example, in their study of large organizations in Italy and Spain, Dumitru et al. (2016) found that "respondents clearly acknowledge this aspect, and feel the need to present themselves and define their identity as 'green', in particular in relation to energy saving" (p. 56). Based on the current study, it seems that identity is a motivator of retrofit investment behaviour that extends across individual and organizational levels, and is prevalent sector-wide within the commercial real estate sector. This individual-centric position is contrary to the Scandinavian context in which Lynes & Andrachuk (2008) found basic social democratic values, including efficiency, and emphasis on societal good over individual good were an important influence when investigating motivations and barriers for corporate social and environmental responsibility.

Regardless of whether the interviewee agreed with retrofit investment decisions or behavioural programs in place (or not) within their building, there was recognition that embracing energy management has been an industry best practice for at least the last ten years.

The importance of owning and operating green assets was also seen in the public-sector interviews, since municipalities and other public-sector institutions operate as large organizations, with the exception that they are service vs. profit-driven. For example, cities drive economic growth by attracting new residents and businesses, therefore the same desire to signal value underlies the explicitly stated purpose of providing service. A European review of the municipal sector identified municipal buildings as the 'heart' or most suitable and available sites for implementing pilot projects on energy optimization and Smart grid technologies (Androulaki, 2016). While the upfront cost of undertaking energy management projects and pursuing certification were clearly key decision-making criteria for most public-sector interviewees, it was generally seen as a necessity for being competitive in the marketplace. Certification to voluntary, best practice standards such as BOMA-Best or LEED was viewed as an opportunity to demonstrate corporate social responsibility. However, the high cost of certification was seen as a barrier for Class B and C buildings, and even some Class A buildings in budget-constrained portfolios. Therefore, addressing this barrier represents another leverage point in the system, whether through a more equitable distribution of certification costs amongst all beneficiaries, or developing alternative signaling methods to convey the green building image that can be accessed at a lower cost while still protecting against green-washing. Effective operationalization of energy management strategies (in both certified and non-certified buildings) was perceived as a distinguishing characteristic of advanced property management firms in both the private and public-sector. This competitive advantage is considerably less relevant for smaller organizations that operate or occupy Class B and C buildings in less desirable locations, or smaller municipalities where high economic growth is not part of a long-term business plan.

4.6.5 Mainstreaming green

The interviews revealed that within this sample population, stakeholders in management positions generally believe that energy efficiency has a significant impact on operational costs, and factors heavily into tenants' decisions to rent commercial office space. Thus mainstreaming green (i.e., influencing social norms and sector-specific perspectives as per Figure 23) is a mode of behaviour that can lead to increased building retrofits (see Mode E in Figure 24 and expanded in Figure 29). The connection between green building features and corporate image may be further explained in terms of public trust in products that have been received external validation from expert arms-length sources, as seen in the connection between Modes D and E in Figure 24. Commercial buildings are tangible objects, and when tenants are looking for office space to rent, third-party certifications such as LEED or BOMA-Best notify interested parties that adherence to the published requirements have been independently verified (Punitha, 2013). Thus, similar to the hotel industry (e.g., Punitha, 2013), building certifications become a green marketing tool for attracting tenants that want to reduce their environmental impacts through their leased office space. Green-certified properties also command rental premiums (Devine & Kok, 2015), increasing both profit (a system sub-goal) and prestige for building owners and property managers.

The findings from this study differed from the attitudes of UK property investors presented by Elliott et al (Elliott et al., 2014), which ranged from energy attributes being "too far away or small" for people to pay attention to being "incredibly important". This may be due to the impact of localized demand drivers such as higher education and incomes, which were found in a study on the magnitude of the marketing signaling effect of LEED certification for green buildings, and the mechanisms leading to certification (Chiang & Noonan, 2017).

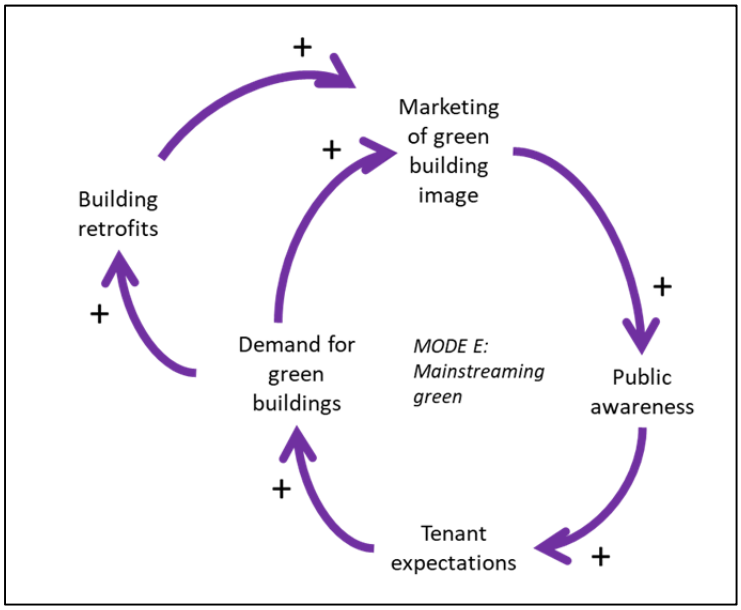

Figure 29: Mode E - Mainstreaming green

4.7 Conclusion

This study investigated the performance gap in commercial office buildings through a systems lens. The perspectives of building owners (via representatives), sustainability officers, property managers, operators, and tenants on retrofit investment and behavioural programs were explored through semi-structured interviews, conducted in the Canadian provinces of Ontario and Alberta, with both private- and public-sector stakeholders. While there is general recognition in the energy behaviour literature that the motivations and barriers for engaging in energy management practices differ according to stakeholder group (e.g., owners vs. tenants), no system-level analyses have previously been offered, in relation to reducing the performance gap in a commercial building. The interdependence of the stakeholder groups and sub-actors within a commercial building and the impact of each group on the sub-goals and overall system goal can be clearly seen in Figure 23, the overview of system components. The systems perspective is crucial to solving complex issues such as the performance gap because interdependent actors need to "collectively appreciate that they are part of a system" and "understand how their actions impact and are impacted by other system members" (Nowell & Foster-Fishman, 2011). System actors and their actions create the conditions for synergy as well as destructive interference with respect to the overall response in addressing

system issues (Nowell & Foster-Fishman, 2011), such as reducing the performance gap in a commercial building.

The results of this study suggest that the ultimate purpose of a commercial building – profit generation or provision of public service – is of fundamental importance to a system-level understanding of energy management, and directly linked to stakeholders' views on retrofit investments and engagement in behavioural programs in the context of their roles and responsibilities. This purpose can be seen as a system sub-goal in the profit generation feedback loops in Figure 28. The common motivator across all stakeholder groups was corporate image, a variable that is also part of the same mode of behaviour and related to leveraging a building's green image for some benefit. Interviewees, who were mainly mid- to senior-level decision-makers, repeatedly listed identity, competitive advantage, pride of place, branding, and being best in class as influencers. These terms carried significant and consistent meaning for them, and identity, competitive advantage, and publicity (i.e., marketing of the corporate brand to increase recognition) were repeated variables within the system feedback processes. Progressive ownership groups were touted as seeing their commercial assets as "reflections of themselves", while property managers claimed "bragging rights" for management of certified high-performance buildings. Tenants employed by an organization with publicized sustainability values also reflected on the alignment of occupying high-performance buildings with their core business strategy.

Notwithstanding, there did not seem to be a shared notion of the level of energy efficiency that constituted 'high-performance' amongst the interviewees, rather this concept appeared to be a continuum based on the baseline condition of a building and the extent to which the individual's organization exhibited sustainability values. For example, in high-demand, downtown locations, interviewees expressed the desire to own, manage, and occupy commercial buildings certified to a minimum level of LEED or BOMA-Best, with Platinum being an aspirational objective. Sometimes the building certification itself was identified as being demanded or expected by tenants, but not always. Tenant groups that were cited as being concerned about the certification of their rented space included banks, law firms, engineering firms, and some high-tech firms. In suburban locations, other factors such as proximity to highways and public transportation, or a heritage designation, were perceived as superseding (or at least being of equal importance to) building certification and the associated high-performance features. However, in suburban (non-heritage) locations, preference for high-efficiency building characteristics – LED lighting, preferred parking for electric and hybrid vehicles, building-level engagement in sustainability initiatives, etc. – was de-coupled from building certification, and linked more closely with the reduction of operating costs and the ability to offer competitive rental rates and service excellence to tenants. In this sample population, tenants whose businesses involved a large manufacturing component (i.e., who would occupy both commercial and industrial properties) were seemingly less concerned with certification, but valued high-efficiency building features as a pathway to improve the efficiency of their operations. These findings suggest that there may be unique socioeconomic and attitudinal characteristics of the sample populations in

this study that are correlated with particular values and attitudes towards retrofit investments and behavioural programming in commercial buildings.

This study also suggests that communication within and between stakeholder groups is critical in obtaining the system-level goal of reducing the performance gap in commercial buildings, and ensuring shared benefits (related to the building's purpose of profit generation or delivery or service). Communication and coordination within and between stakeholder groups (see Figure 23) were both direct and indirect influencers of sub-actor decision-making and behaviour, and influenced the sub-goals of the system, as well as the overall system outcome with respect to the performance gap. Both retrofit projects and energy management behavioural programs were seen as opportunities to develop and nurture relationships within the building system. Property managers used various communication methods to engage with their operations staff and tenants to provide information and training, in order to increase awareness and build capacity within the system. In some cases, projects or initiatives produced win-win-win scenarios for the system. For example, an installed solar project created energy savings and reduced GHG emissions, while increasing the asset value of the building and the reputation of the owner, property manager, and tenants. The literature has shown that adding value to a building through investments in energy retrofits can strengthen the relationship between landlords and tenants (e.g., Greenough & Tosaratti, 2014).

In this sample population, the absence or breakdown of communication was shown to have unintended consequences that were detrimental to the achievement of the system goal, and created tension in the relationships between building stakeholders. As so many system functions (recall Figure 23) are dependent on effective communication (the provision of expert knowledge and stakeholders sharing their perspectives with each other), a robust building-level engagement strategy is important to reduce the barriers to the adoption of retrofit investments and behavioural programming in commercial buildings. In this study, some engagement initiatives that were intended to foster relationships with tenants appeared to create tension, particularly when tenants were simply informed about certain events instead of being involved in their design and implementation. This finding reinforced empirical evidence that decision-makers should use participatory intervention designs rather than top-down promotion of energy savings to facilitate consumer (in this case, employee) participation through increased intrinsic motivation at the individual level (e.g., Endrejat et al., 2015). In this case, not only did the approach taken by the property manager not lead to the desired system outcome, it may have damaged their relationship with the tenant. Repeated instances may eventually decrease the likelihood of a lease renewal, although there was no such indication in this particular case.

The application of systems thinking in this study to characterize energy management decision-making within a commercial office building has provided utility in analyzing the interconnections between all of the major stakeholders simultaneously, along with multiple modes of behaviour that can lead to the desired outcome of increased retrofit investments. The management literature has shown that even under the most optimistic conditions of stable distribution of goods and commonly understood demand, individuals within a product supply chain have limited cognition to manage the

complexities of a dynamic system, resulting in the 'bullwhip effect', or amplification of oscillation of higher orders in a supply chain system (Forrester, 1958; Croson & Donohue, 2006). While energy management within an office building is not a supply chain issue, the bullwhip effect offers explanatory power of the impact of both positive and negative engagement occurrences within the building system, particularly with respect to increasing or decreasing the performance gap. This systems analysis has also provided insight into potential leverage points that may reduce the barriers to retrofit investment and therefore the performance gap. Policy makers and advocacy groups seeking to have a significant impact on the performance gap should conduct further research on innovative funding mechanisms to reduce the initial capital cost of high-performance equipment and the high cost of green certification, in order to reduce the barriers to large retrofit investments for smaller building owners and managers. At the building-level, sustainability teams are a good starting point for knowledge mobilization, provided membership includes key decision-makers from each stakeholder group, and that the engagement process is well-defined and includes knowledge mobilization strategies. Knowledge transfer agreements (i.e., to share energy management system feedback and utility consumption/billing data) would also facilitate more effective troubleshooting of building control systems by operations staff that affect overall performance and thermal comfort.

4.7.1 Limitations & Future Research

Acknowledging the inherent sampling bias in this sample set, where participants were drawn from the membership of two organizations that advocate for sustainability in the commercial building sector, this study nevertheless suggests that developing a systems-view of the motivations and barriers for engaging in energy management initiatives may be relevant in the broader Canadian and North American context. Future research could aim to test the hypotheses suggested by this study with a much larger sample set (preferably at the national level), including smaller organizations that operate or occupy Class B and C buildings in less desirable locations, and/or smaller municipalities and other public-sector institutions where high economic growth is not part of a long-term business plan. A systems conceptualization that is representative of the nation's existing building stock would be a useful tool for developing interventions to further reduce the barriers to sustainable energy management in the commercial buildings sector.

Chapter 5 – Conclusion

This chapter reviews and synthesizes the overall significant, original contribution to knowledge made through this research. The purpose and objectives of the research are first reviewed. The primary findings from the previous three chapters, presented as individual research manuscripts, are then summarized and synthesized into overarching conclusions related to an intervention-based approach to energy management at various scales. The significant, original, and interesting contributions to knowledge are then summarized, from the academic and applied perspectives. The chapter concludes with a discussion of the study limitations and ideas for potential areas of future research.

5.1 Purpose and Objectives

The purpose of this research was to investigate the success factors and barriers to the achievement of GHG emissions reductions in Ontario and Alberta through an intervention-based analysis. A scoping review was first used to establish the important/influential communities of scholarship that shape the structure of the pro-environmental behaviour (PEB) change literature, and to assess the extent to which current research fronts in the field reflect the themes identified in the publications that define the field. An assessment of how these themes have been applied in the design and implementation of interventions to encourage PEB was then made. Two empirical cases were then used to gain insights into the implications of intervention design and implementation from different stakeholder perspectives.

This study included the following specific objectives:

1. To understand and create a network visualization of the current application of pro-environmental behaviour change literature, examining the implications for intervention design and implementation and CDM public policy;
2. To empirically examine Ontario's CDM results (as a case study of intervention design and implementation), specifically, the achievements of the province's local distribution companies (LDCs) with respect to 2011-2014 Peak and Cumulative Demand Targets, as per the Conservation First Framework; and
3. To empirically examine the motivations and barriers of various stakeholders in the commercial buildings sector to engagement in energy management initiatives, including similarities and differences that may arise from various contexts (as a second case study).

5.2 Major Findings

Research findings were presented in three manuscripts. In this section, the major findings from each manuscript are provided.

5.2.1 Chapter Two

Chapter Two used a scoping review methodology (Grant & Booth, 2009) to examine the literature on pro-environmental behaviour change to determine the influential/important communities of

scholarship that shape the structure of the field, and the extent to which emerging research fronts reflect the structural themes. The goal of Chapter Two was to determine the implications of the utilization of environmental behaviour change theory in the design and implementation of interventions on the achievement of desired behavioural outcomes. The results of this study revealed that the Journal of Social Issues (JSI) 2000 Vol. 56 Issue 3 was a compilation of important/influential papers, measured by co-citation analysis, bibliometric coupling analysis, and four types of centrality. A dense, six-cluster network was revealed, with two papers from this special issue by Stern and Dunlap & Van Liere forming the lobes of the structure. The four themes identified by the editors of the JSI 2000 special issue – synthesis, motives/values, power, and applicability – were found to generally map onto the structural network, with two clusters primarily dedicated to synthesis, one each for the other themes, and one cluster comprised of a combination of three themes (synthesis, motives/values, and applicability). At the article level, the breakdown of themes was 45% synthesis, 34% motives/values, 8% power, and 13% applicability. This reinforces the findings from the network visualization of the structure of the field, which indicates a focus on advancement of existing models, instruments and theoretical frameworks that explain and predict antecedents of behaviour and behavioural outcomes, versus the use of this knowledge on environmental justice issues and solutions to anthropogenic climate change, more broadly.

Chapter Two also revealed that the emerging research fronts reflect a stronger focus on the applicability of environmental behaviour change theories on salient issues such as consumerism (Hirsh & Dolderman, 2007), household (Abrahamse & Steg, 2011) and workplace energy (Greaves et al., 2013) consumption, transportation choice, and tourism (Dolnicar & Leisch, 2008).

Many issues remain, which were outside of the scope of this analysis of the literature. Using the lens of importance/influence (as defined by citations in peer-reviewed publications) to examine the literature revealed the structure of the field as academic researchers themselves have defined it and their roles within it. Chapter Two establishes a need to examine the literature through a systems lens (Karlsson-Vinkhuyzen et al., 2012) in order to establish the extent to which impacts at the infrastructure, institutional, and individual levels are being addressed, and what knowledge exists about designing and implementing interventions at these levels. All of these levels have consequences for the potential achievement of desired socio-ecological outcomes.

5.2.2 Chapter Three

Chapter Three was the first of two chapters to empirically address the identified gap related to consequences of intervention design and implementation through a case study: the variability of electric distribution utility achievement and rate of achievement of conservation and demand management (CDM) targets was examined in the province of Ontario. Utilities are highly regulated decision-making units (Charnes et al., 1978) that are often mandated and/or incentivized through regulatory instruments to achieve CDM outcomes through the reduced consumption of their customers (Thoyre, 2015). Utilities therefore control many aspects of stakeholder engagement, and are an important facilitator of interventions to study.

In this case study, a multi-level growth curve model was used to explain the achievement and rate of achievement of the provincial Peak Demand and Cumulative Energy Savings targets by Ontario's local distribution companies (LDCs). Longitudinal data from 2011-2014, measured and reported for each individual LDC was entered at the lower level (Level-1) of the model. Level-2 of the model compared the variability between the LDCs. Since this was the first study assessing the CDM performance of LDCs, the independent variables were drawn from the econometrics literature on the conventional benchmarking of electric distribution utilities (e.g., Cronin, 2007; Cui, Kuang, Wu, & Li, 2014; Kushner & Ogwang, 2014; Pahwa, Feng, & Lubkeman, 2002). It was hypothesized that independent variables used to benchmark the conventional performance of electric distribution utilities might also explain the CDM performance by Ontario's LDCs. While there was insufficient variance in the data to allow for analysis of the Peak Demand target, the model revealed statistically significant variability in the cumulative achievement of the Cumulative Energy Savings target, as well as the rate of change towards the target over a four-year period. More importantly, the statistically significant variance of the rate of change over time suggests that LDCs moved towards their respective targets at different rates. This variance was largely left unexplained by the multi-level model developed in this case study, therefore opportunities remain to improve the model and offer further insight into Ontario's energy conservation landscape at this level of the energy system.

5.2.3 Chapter Four

While Chapter Three investigated CDM with electric utilities as the unit of analysis, Chapter Four shifted analytical lenses away from electricity distribution to the end use of energy in commercial office buildings. The goal of Chapter Four was to apply systems theory (Meadows, 2009) to the investigation of opportunities to reduce the performance gap in commercial office buildings. Systems theory was used to characterize the boundaries of the system and the system components, such as the stakeholders and norms, resources, regulations and operations that are potential root causes of the phenomena of interest. This study used qualitative empirical data from Ontario and Alberta, two provinces with different electricity grid compositions, electricity prices, and levels of energy consumption. A conceptual overview of the relationships among system components was developed, and five modes of behaviour were identified as pathways for increasing the investment in building retrofits and stakeholder engagement in energy behaviour programs. Key findings revealed that the objectives of stakeholders in the commercial real estate sector are determined by their roles (owner/executive, property manager, sustainability officer, operator, or tenant) and the sector (private or public). A commercial building was seen to have one of two purposes – profit-generation or utility in the provision of public services – which ultimately framed stakeholders' objectives and decisions regarding energy management. Regulations, social norms, sector- and location-specific factors influence these objectives. When viewing a building as a system, the results revealed multiple layers of relationships that influence energy management decision-making, including both formal and informal processes. The split-incentive has been well-documented in the literature (e.g., Astmarsson, Jensen, & Maslesa, 2013), and was reiterated in the findings of this study, where relationships were both motivations and barriers to engaging in energy management. Interaction effects were demonstrated such that the actions of one stakeholder group to promote building-level

energy management were seen as a barrier for another stakeholder group to actively engage achieving the shared outcome of energy savings. A systems perspective was required to observe these interaction effects.

Buildings that are designed and built to meet "green" certification status (e.g., LEED or BOMA Best) are often viewed as superior, commanding rent premiums (Devine & Kok, 2015). However, the actual achievement of the estimated levels of energy savings associated with certification levels goes beyond design, and is highly dependent on building managers and operators to tightly measure and monitor the building systems, and for occupants to use high-efficiency technologies as they were intended (Fedoruk et al., 2015). Failure to do so leads to the performance gap within buildings (Fedoruk et al., 2015). A major finding from Chapter Four is that the performance gap cannot be adequately addressed at the employee scale, alone, or by investigating any one scale in isolation of the other stakeholders. In this sample population, evidence of collaboration between stakeholders to discuss shared benefits and outcomes, creating win-win scenarios, mitigated some of the split-incentive challenges that have been documented in the literature (Martin & Gossett, 2013).

5.3 Contributions

5.3.1 Academic Contributions

This study contributes to two important research topics identified in the academic and grey literature. First, it addresses the performance gap as a 'wicked' problem that requires unprecedented levels of cross-sector co-operation in order to be resolved (Buanes & Jentoft, 2009). The synthesis of findings from Chapters Two and Four of this study suggest that energy efficiency and conservation is an emerging research front within the pro-environmental behaviour change literature; using a systems framework to address the increasing number of time-sensitive issues, such as the transformation to a sustainable energy future, could be effective in achieving desired voluntary behavioural modifications.

In the case of commercial buildings, this finding addresses comments from the literature that the psychological factors that influence individual behaviour in organizational settings are ineffectively integrated into energy conservation programming (Endrejat, Klonek, & Kauffeld, 2015; Fedoruk et al., 2015) despite general agreement that there are multiple determinants of sustainable behaviour in organizations (Lülfs & Hahn, 2014; F. McDonald, 2014). The limited empirical evidence of systems theory being applied to reduce the performance gap in commercial buildings points to a historical tendency for siloed approaches to problem resolution. Researchers have studied interventions targeted at segmented stakeholders such as building owners/investors (Elliott et al., 2014; Gliedt & Hoicka, 2015) or employees/co-workers (Paillé, Mejía-Morelos, Marché-Paillé, Chen, & Chen, 2016), but few have modelled buildings or organizations holistically. Notable exceptions are Kim et al., (2017) who developed and tested a multilevel model of voluntary workplace green behavior in organizational settings, with a focus on the behaviour of group leaders and individual group members, and Fedoruk et al. (2015) who analyzed the design process and operational performance of

the Centre for Interactive Research on Sustainability (CIRS) building at the University of British Columbia from an energy systems perspective.

Chapter Four – an empirical case contributed to the existing body of literature – positioned a commercial office building as a bounded system (Foster-Fishman et al., 2007), characterizing the stakeholder groups and sub-actors within a sample population of the commercial real estate sector and their respective goals/objectives for the building, in order to address the performance gap. Drawing from the principles of systems theory, in order to implement system-level changes to produce mutually beneficial outcomes, it is critical that stakeholders acknowledge their position, roles and responsibilities within a system (and the consequences of their actions on other system components) (Meadows, 2009), and commit to collaborative approaches to addressing system-level problems. A major finding from this case study is that stakeholders' motivations and barriers for engaging in energy management initiatives are fundamentally shaped by the perception of a building's purpose, either profit-creation or the provision of institutional services. This positioning, along with the stakeholders' roles in the management, operation, or occupancy of the building significantly influenced the focus on the system objective of reducing the performance gap and the associated greenhouse gas emissions. This study reinforced literature on the split-incentive in commercial buildings, and the financial and relationship challenges faced in developing a more sustainable commercial real estate market (e.g., Martin & Gossett, 2013). One original contribution of this work is the identification of five major modes of behaviour at the system-level that can lead to increased retrofit investments in commercial buildings. Within these modes of behaviour, three leverage points (the high cost of capital improvements, the critical role of operator capacity, and the high cost of green-certification) were identified as targeted opportunities for interventions to reduce the barriers to retrofit investments in commercial buildings.

Second, this study also contributes an empirical case – Chapter Four – to the literature on the cost-effectiveness of government-funded CDM programs and whether these programs are returning the desired improvements in social and environmental outcomes (Gillingham et al., 2006; Thomas & Sharp, 2013). The synthesis of findings from Chapters Two, Three, and Four of this study suggest that a system-level investigation of the conservation and demand management (CDM) performance of Ontario's local distribution companies (LDCs) could potentially explain the statistically significant variation in both achievement and the rate of change towards CDM targets that was observed from 2011-2014. While researchers have examined the determinants of utilities' costs and distribution reliability in this jurisdiction (Francis J. Cronin & Motluk, 2011; Frank J. Cronin, 2007; Kushner & Ogwang, 2014), there is limited empirical evidence of CDM metrics being used to benchmark electric distribution utilities the Canadian context or any other jurisdiction. Chapter Three represented an original contribution to knowledge as the first quantitative analysis of the variability of achievement and rate of achievement of provincially regulated conservation and demand management (CDM) targets by Ontario's LDCs. The findings from this study revealed that in the Ontario context, conventional financial and operational benchmarking indicators were unable to explain the majority of variance in CDM achievement and the rate of change between LDCs.

Determining variables that influence the achievement of CDM metrics would contribute to the design and implementation of public policy aimed at improving energy efficiency and conservation, and improve the cost-effectiveness of these programs. As was suggested by the case study focused on the commercial buildings sector, a systems framework could illuminate modes of behaviour that may increase the likelihood of stakeholder collaboration in the pursuit of system-level energy efficiency and conservation in the electricity distribution sector.

Returning to the overarching research question presented in Chapter One of the implications for intervention design and implementation and CDM public policy, the following key conclusions emerged from the synthesis of Chapters Two, Three and Four:

1. *Intrinsic motivation is more effective for sustaining desired behaviour change.*

Two different generalized approaches to energy research were observed in Chapter Two: papers on energy conservation and energy efficiency (embedded within structure of the pro-environmental behaviour field) were largely works of model/theory development, review of the extant literature and predictive power of models, and application of theories in case studies; papers on renewable energy (present in the emerging research fronts) explored societal values, including place attachment and quality of life, and the implications of those values on human responses to climate change. The recent focus on pro-environmental behaviour (PEB) as a societal issue in academic research resonates with the finding from the case study presented in Chapter Four, that tenants in the commercial real estate sector want to be active participants in the development and implementation of energy management initiatives within their occupied buildings. While place attachment and connectedness to nature are more often associated with the natural environment, there is increasing evidence of the benefits of indoor nature-based experiences, and the development of place attachment to high-quality indoor environments (e.g., Dreyer, Coulombe, Whitney, Riemer, & Labbé, 2018). As such, the synthesis of the findings from Chapters Two and Four suggest that desired behaviour change should be intrinsically motivated (in this case, emphasizing one's desire for community and biospheric concern) for sustained impact, as other researchers have suggested (e.g., Ryan & Deci, 2000).

2. *Interventions focused on extrinsic motivations can be difficult to sustain over the long-term.*

Building upon the need for behaviour change to be intrinsically motivated for sustained impact, it follows that interventions focused on extrinsic motivations such as financial incentives are comparatively more difficult to sustain over the long-term, because the behaviour does not become internally regulated, and thus requires the continued presence of the extrinsic motivator or 'reward' (e.g., Lehman & Geller, 2004; Ryan & Deci, 2000). This is due to the requirement for external regulation. However, the Government of Ontario's conservation and demand management (CDM) program is essentially comprised of a suite of financial incentive programs to support the province's LDCs in their promotion of CDM within their service territories. The synthesis of the findings from Chapters Two and Three, suggest that other forms of interventions may be more effective in achieving the province's goals. Notwithstanding, one finding from Chapter Four is that the capital

(and sometimes operational) costs of, and lack of funding mechanisms for energy retrofit investment were prohibitive in the commercial real estate sector. This finding appears to further support the common public policy direction to provide some form of economic stimulus to encourage behaviour change in this area.

3. *Stakeholder engagement strategies should focus on developing a culture of energy management within the system of interest.*

The increasing role of normative influence on pro-environmental behaviour was recognized in Chapter Two, including the importance of signaling individual identity, the enduring effect of public commitments to change, and the role of socialization in individual decision-making, more broadly. These findings from Chapter Two, in combination with the identification of green building image and identity as underlying motivators for stakeholders in the commercial real estate sector in Chapter Four, serve to highlight the importance of developing a culture of energy management within commercial buildings as the bounded system of interest. If sustainable energy management was embedded in the dominant culture, such that it offered individuals and organizations the desired intrinsic value (e.g., competence, personal growth, and community acceptance), the split-incentive issue and other barriers would be reduced. The findings from Chapter Four suggest that extrinsic aspirations such as prestige and status (and associated competitive advantage) are still prominent motivators, due to their signaling value and their perceived indirect financial benefits. Thus, intractable tension remains between the ideal scenario and current reality within the system context.

5.3.2 Recommendations for Practice

Interventions to encourage energy conservation behaviour are widely applied at all scales in industrialized nations, globally. Within the province of Ontario, a number of other studies have been explored other pathways to reduced GHG emissions, such as socio-technical transition to a low-carbon electricity sector (Rosenbloom & Meadowcroft, 2014), the evolution of Smart Grid policy (Winfield & Weiler, 2018), and the behavioural effects of electricity sub-metering (Gunay, O'Brien, Beausoleil-Morrison, & Perna, 2014). Several recommendations emerged from this study for practitioners involved in designing, implementing energy conservation interventions. These recommendations are directly derived from empirical findings.

1. *When benchmarking CDM performance, consider 'unconventional' metrics.*

Electric distribution utilities can be viewed as decision-making units within an energy conservation program as having common inputs and outputs (Charnes et al., 1978). The findings from Chapter Three suggest that the conventional financial and operational metrics that are used to benchmark the performance of electric distribution utilities are, at least in the Ontario context, insufficient for explaining the statistically significant variation in both CDM target achievement and the rate of change towards a cumulative target over time. This suggests that other inputs (which may or may not be common amongst the utilities within a given jurisdiction) may have greater predictive power with respect to benchmarking CDM performance. Drawing from the findings of Chapter Four, the leadership context may be an important factor to consider when analyzing CDM performance of

utilities. This aligns with previous studies that found the underestimation of internal priority setting to be a barrier to large-scale energy efficiency projects in the services sector (Schleich, 2009).

More generally, the leadership context within organizational settings (e.g., leadership support for and modelling of exemplary pro-environmental behaviour) has been shown in the literature to lead to desired behavioural outcomes, such as increased workplace pro-environmental behaviour by employees and more positive job attitudes overall (e.g., Blok, Wesselink, Studynka, & Kemp, 2015; Lamm, Tosti-Kharas, & King, 2015). The leadership context of an organization, when measured, is often reporting as part of the organization's corporate social responsibility (CSR) strategy. A recommendation for practice includes making use of such data in future efforts to benchmark the CDM performance of electric distribution utilities.

2. *Apply a systems framework to identify modes of behaviour for achievement of desired outcomes.*

Individuals and organizations are part of complex and nested social networks, where environmental behaviour is influenced by interactions and relationships, including conflicting interests and incentives (e.g., Janda, Bright, Patrick, Wilkinson, & Dixon, 2016). The findings from Chapter Four suggest that applying a systems framework to a desired outcome, such as reducing the performance gap in commercial office buildings, can be useful in identifying modes of behaviour or pathways for the achievement of the desired outcome. Several systems frameworks were presented in Section 4.2.3 of this paper, and may be useful resources for practitioners interested in integrating systems theory into their work. Following the methodology from Chapter Four, a general systems framework may include the following four steps:

1) Problem identification: Bounding or scoping the system and the overall system goals(s);
2) Identification of the major system actors: Stakeholder groups and sub-actors that influence the achievement of the overall system goal(s);
3) Assessment of relevant system interactions: Reinforcing and balancing feedback loops, including internal and external drivers for the major system actors; and
4) Identification for leverage points within the system: Opportunities for influencing system change at various levels (individual actor(s), cross-level).

3. *Identify leverage points from system-level modes of behaviour for targeted interventions to improve desired outcomes.*

Once system-level modes of behaviour or pathways that can lead to the desired behavioural outcome are established, leverage points can be identified for targeted interventions (to a subset of the system boundary and/or a segment of the sub-actors) to improved desired outcomes.

One finding from Chapter Four suggests that the capital (and sometimes operational) costs of, and lack of funding mechanisms for energy retrofit investment are a barrier to retrofit investment in the commercial real estate sector, at least in the Ontario and Alberta context. This finding appears to

further support the common public policy direction to provide some form of economic stimulus to encourage behaviour change in this area. However, deeper exploration of the 'voluntary infrastructure improvements mode of behaviour' suggested that the existing levels of financial incentives are insufficient for overcoming the barrier to large retrofit investments (recall from Chapter Four that the incentives available for chillers and boilers are less than 5% of the capital cost). As such, an innovative funding mechanism (e.g., loans paid in part through energy cost savings) could make strides in reducing this barrier.

5.4 Study Limitations and Ideas for Future Research

Many interesting research questions were raised throughout the study process that are beyond the scope of the manuscripts presented in Chapters Two, Three, and Four. For example, mandatory reporting of energy efficiency in rental markets has been proposed as a policy intervention to increase investments in building retrofits (Burfurd, Gangadharan, & Nemes, 2012), along with better benchmarking and reporting of retrofit projects (Dixon, 2014). However, as with other climate change policies, the energy efficiency and conservation discourse has become individualized, limiting the degree of social change surrounding the issue (Corner & Randall, 2011). Further investigation into mandated energy performance certificates or equivalent (Axon, Bright, Dixon, Janda, & Kolokotroni, 2012) would be helpful in determining the feasibility of Canadian strategies to address the split-incentive issues within commercial real estate.

Private sector interviewees frequently made reference to the need obtain or maintain competitive advantage in order to be successful at securing long-term leases and generate profit for building owners. Prestige and bragging rights were other forms of signaling identity that were associated with owner or managing high-value assets. A more thorough review of the commercial real estate literature is required to determine how to intrinsically motivate (Ryan & Deci, 2000) owners of smaller and older properties in less desirable rental markets in the absence of rental premiums for energy efficiency.

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Appendix A

Full Boolean Search in Web of Science

Name: Broad literature Mar **Database:** Web of Science Core Collection

Description:

Query: (TS=(environmentalism) OR TS=(environmental NEAR/5 (behaviour OR behavior)) OR TS=((pro-environmental OR proenvironmental) NEAR/0 (behaviour OR behavior)) OR TS=(((behaviour OR behavior) AND change) AND (environmental OR sustainability)) OR TS=((environmentally significant) NEAR/5 (behaviour OR behavior))) *AND* **LANGUAGE:** (English)
Refined By: **DOCUMENT TYPES:** (ARTICLE) AND **[excluding]:WEB OF SCIENCE CATEGORIES:** (POLYMER SCIENCE OR BIOTECHNOLOGY APPLIED MICROBIOLOGY OR PEDIATRICS OR CHEMISTRY ANALYTICAL OR CLINICAL NEUROLOGY OR FISHERIES OR MATERIALS SCIENCE COMPOSITES OR ZOOLOGY OR NUTRITION DIETETICS OR ENGINEERING ELECTRICAL ELECTRONIC OR PUBLIC ENVIRONMENTAL OCCUPATIONAL HEALTH OR METEOROLOGY ATMOSPHERIC SCIENCES OR FORESTRY OR NEUROSCIENCES OR AGRICULTURE DAIRY ANIMAL SCIENCE OR HEALTH CARE SCIENCES SERVICES OR GEOGRAPHY PHYSICAL OR SUBSTANCE ABUSE OR PHYSIOLOGY OR TRANSPORTATION SCIENCE TECHNOLOGY OR MARINE FRESHWATER BIOLOGY OR ENGINEERING CHEMICAL OR MATHEMATICAL COMPUTATIONAL BIOLOGY OR MATERIALS SCIENCE MULTIDISCIPLINARY OR CHEMISTRY MULTIDISCIPLINARY OR PSYCHOLOGY EXPERIMENTAL OR ENDOCRINOLOGY METABOLISM OR MICROBIOLOGY OR SOIL SCIENCE OR PLANT SCIENCES OR COMPUTER SCIENCE ARTIFICIAL INTELLIGENCE OR PSYCHOLOGY DEVELOPMENTAL OR GEOCHEMISTRY GEOPHYSICS OR PSYCHOLOGY BIOLOGICAL OR COMPUTER SCIENCE INTERDISCIPLINARY APPLICATIONS OR BIOLOGY OR PSYCHOLOGY CLINICAL OR HEALTH POLICY SERVICES OR CELL BIOLOGY OR AGRONOMY OR WATER RESOURCES OR MEDICINE GENERAL INTERNAL OR ORNITHOLOGY OR VETERINARY SCIENCES OR ENGINEERING MULTIDISCIPLINARY OR CHEMISTRY APPLIED OR BIOCHEMICAL RESEARCH METHODS OR OCEANOGRAPHY OR MECHANICS OR METALLURGY METALLURGICAL ENGINEERING OR EVOLUTIONARY BIOLOGY OR PHYSICS APPLIED OR REHABILITATION OR FOOD SCIENCE TECHNOLOGY OR URBAN STUDIES OR TOXICOLOGY OR ANTHROPOLOGY OR INSTRUMENTS INSTRUMENTATION OR CHEMISTRY PHYSICAL OR ENGINEERING MECHANICAL OR BIOCHEMISTRY MOLECULAR BIOLOGY OR ENTOMOLOGY OR MEDICINE RESEARCH EXPERIMENTAL OR BIODIVERSITY CONSERVATION OR AGRICULTURE MULTIDISCIPLINARY OR NURSING OR NANOSCIENCE NANOTECHNOLOGY OR LIMNOLOGY OR PHARMACOLOGY PHARMACY OR ETHICS OR NUCLEAR SCIENCE TECHNOLOGY OR GENETICS HEREDITY) AND **[excluding]: WEB OF SCIENCE CATEGORIES:** (RELIGION OR INFORMATION SCIENCE LIBRARY SCIENCE OR COMPUTER SCIENCE SOFTWARE ENGINEERING OR COMPUTER SCIENCE INFORMATION SYSTEMS OR COMPUTER SCIENCE THEORY METHODS OR AREA STUDIES OR GEOLOGY OR OPERATIONS RESEARCH MANAGEMENT SCIENCE OR PHILOSOPHY OR PHYSICS MATHEMATICAL OR SPORT SCIENCES OR THERMODYNAMICS OR MATERIALS SCIENCE BIOMATERIALS OR CRIMINOLOGY PENOLOGY OR ARCHITECTURE OR PHYSICS MULTIDISCIPLINARY OR FAMILY STUDIES OR GERIATRICS GERONTOLOGY OR REMOTE SENSING OR INFECTIOUS DISEASES OR COMPUTER SCIENCE CYBERNETICS OR ENGINEERING BIOMEDICAL OR OPTICS OR ART OR LITERATURE OR PHYSICS CONDENSED MATTER OR MATERIALS SCIENCE CERAMICS OR TELECOMMUNICATIONS OR TROPICAL MEDICINE OR ARCHAEOLOGY OR DENTISTRY ORAL SURGERY MEDICINE OR GEOSCIENCES MULTIDISCIPLINARY OR GERONTOLOGY OR PHYSICS FLUIDS PLASMAS OR MATHEMATICS INTERDISCIPLINARY APPLICATIONS OR ROBOTICS OR DERMATOLOGY OR DEVELOPMENTAL BIOLOGY OR OBSTETRICS GYNECOLOGY OR STATISTICS PROBABILITY OR SURGERY OR HISTORY PHILOSOPHY OF SCIENCE OR WOMEN S STUDIES OR ONCOLOGY OR ALLERGY OR ENGINEERING MANUFACTURING OR AUTOMATION CONTROL SYSTEMS OR IMMUNOLOGY OR BEHAVIORAL SCIENCES OR AGRICULTURAL ECONOMICS POLICY OR CHEMISTRY INORGANIC NUCLEAR OR DEMOGRAPHY OR INDUSTRIAL RELATIONS LABOR OR ELECTROCHEMISTRY OR RESPIRATORY SYSTEM OR MATHEMATICS APPLIED OR GASTROENTEROLOGY HEPATOLOGY OR ENGINEERING GEOLOGICAL OR CULTURAL STUDIES OR ENGINEERING INDUSTRIAL OR BIOPHYSICS OR IMAGING SCIENCE PHOTOGRAPHIC TECHNOLOGY OR PARASITOLOGY) AND**[excluding]: WEB OF SCIENCE CATEGORIES:**(MULTIDISCIPLINARY SCIENCES) AND **[excluding]: WEB OF SCIENCE CATEGORIES:** (ECOLOGY) AND **[excluding]: WEB OF SCIENCE CATEGORIES:** (MATERIALS SCIENCE CHARACTERIZATION TESTING OR LITERATURE AMERICAN OR SPECTROSCOPY OR OTORHINOLARYNGOLOGY OR MATERIALS SCIENCE TEXTILES OR PSYCHOLOGY PSYCHOANALYSIS OR ASTRONOMY ASTROPHYSICS OR ANESTHESIOLOGY OR AGRICULTURAL ENGINEERING OR CHEMISTRY ORGANIC OR MATERIALS SCIENCE PAPER WOOD OR CRITICAL CARE MEDICINE OR ACOUSTICS OR ENGINEERING MARINE OR HEMATOLOGY OR OPHTHALMOLOGY OR LANGUAGE LINGUISTICS OR HORTICULTURE OR LITERARY THEORY CRITICISM OR PALEONTOLOGY OR MATERIALS SCIENCE COATINGS FILMS OR UROLOGY NEPHROLOGY OR MEDICAL INFORMATICS OR MINING MINERAL PROCESSING OR PERIPHERAL VASCULAR DISEASE OR SOCIAL SCIENCES MATHEMATICAL METHODS OR ANDROLOGY OR CARDIAC CARDIOVASCULAR SYSTEMS OR CHEMISTRY MEDICINAL OR EDUCATION SCIENTIFIC DISCIPLINES OR CRYSTALLOGRAPHY OR LITERARY REVIEWS OR MEDICINE LEGAL OR REPRODUCTIVE BIOLOGY OR MINERALOGY OR ASIAN STUDIES OR ANATOMY MORPHOLOGY OR CLASSICS OR FILM RADIO TELEVISION OR LITERATURE ROMANCE OR RHEUMATOLOGY OR MEDICAL LABORATORY TECHNOLOGY OR AUDIOLOGY SPEECH LANGUAGE PATHOLOGY OR MUSIC OR ENGINEERING PETROLEUM OR MYCOLOGY OR LITERATURE AFRICAN AUSTRALIAN CANADIAN OR PHYSICS ATOMIC MOLECULAR CHEMICAL OR MICROSCOPY OR VIROLOGY OR ORTHOPEDICS OR EMERGENCY MEDICINE OR ETHNIC STUDIES OR LITERATURE GERMAN DUTCH SCANDINAVIAN OR LINGUISTICS OR MEDICAL ETHICS OR RADIOLOGY NUCLEAR MEDICINE MEDICAL IMAGING OR NEUROIMAGING OR THEATER OR PATHOLOGY OR ENGINEERING OCEAN OR POETRY OR INTEGRATIVE COMPLEMENTARY MEDICINE OR PSYCHOLOGY MATHEMATICAL OR ENGINEERING AEROSPACE) AND**[excluding]: WEB OF SCIENCE CATEGORIES:** (PSYCHIATRY) AND**[excluding]: WEB OF SCIENCE CATEGORIES:** (ENGINEERING ENVIRONMENTAL) AND **[excluding]: WEB OF SCIENCE CATEGORIES:** (ENVIRONMENTAL SCIENCES) AND **[excluding]:WEB OF SCIENCE CATEGORIES:** (ENGINEERING CIVIL) AND **WEB OF SCIENCE CATEGORIES:** (POLITICAL SCIENCE)

Appendix B

Sample of Keyword Frequency Analysis (Cluster 5)

Text Analyzer

Free software utility which allows you to find the most frequent phrases and frequencies of words. Non-English language texts are supported. It also counts n characters, sentences and syllables. Also calculates lexical density.

Number of characters (including spaces) :	3124
Number of characters (without spaces) :	2663
Number of words :	305
Lexical Density :	55.0820
Number of sentences :	1
Number of syllables :	965

Some top phrases containing 5 words (without punctuation marks)	Occurrences
environmental behavior environmental knowledge environmental	2

Some top phrases containing 4 words (without punctuation marks)	Occurrences
energy education energy literacy	2
environmental behavior environmental knowledge	2
behavior environmental knowledge environmental	2
environmentally responsible behavior environmental	2

Some top phrases containing 3 words (without punctuation marks)	Occurrences
environmental behavior environmental	4
structural equation modeling	3
environmental attitudes environmental	3
responsible behavior environmental	2
education energy literacy	2
behavior environmental knowledge	2
environmental knowledge environmental	2
environmentally responsible behavior	2
energy education energy	2

Some top phrases containing 2 words (without punctuation marks)	Occurrences
environmental concern	6
behavior environmental	6
environmental behavior	6
environmental attitudes	4
ecosystem services	4
equation modeling	3
gender environmental	3
environmental knowledge	3
attitudes environmental	3
structural equation	3
environmental policy	2
environmental behaviour	2
environmental values	2
deliberative valuation	2
responsible behavior	2
education energy	2
energy education	2
shared values	2
energy literacy	2
attitudes environment	2
cross national	2
knowledge environmental	2
pro environmental	2
environmentally responsible	2
values social	2

green marketing	2

Unfiltered word count:

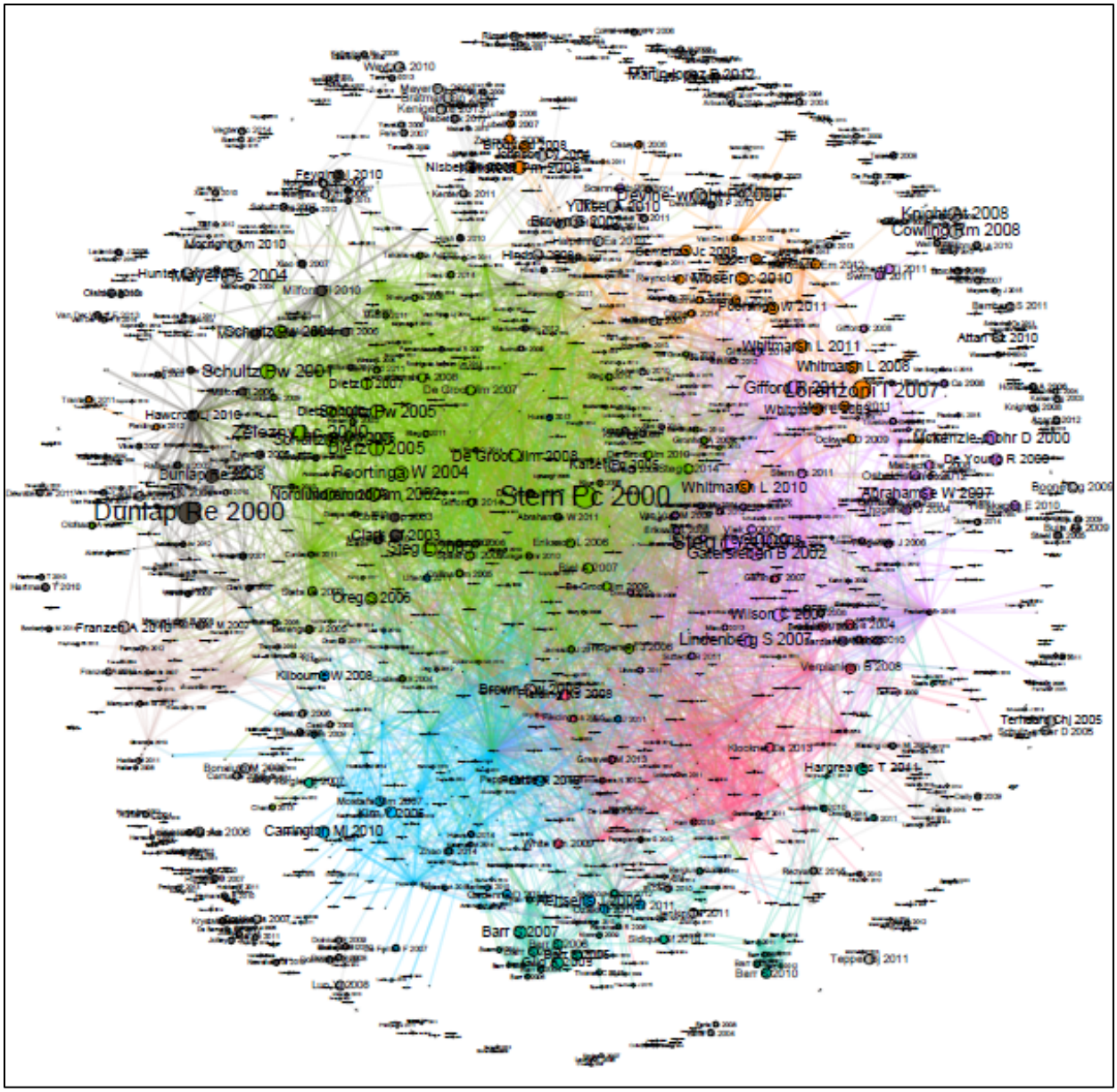
Order	Unfiltered word count	Occurrences	Percentage
1.	environmental	36	11.8033
2.	behavior	8	2.6230
3.	social	8	2.6230
4.	gender	7	2.2951
5.	values	7	2.2951
6.	attitudes	7	2.2951
7.	concern	7	2.2951
8.	ecosystem	5	1.6393
9.	energy	5	1.6393
10.	environment	5	1.6393
11.	value	4	1.3115
12.	knowledge	4	1.3115
13.	services	4	1.3115
14.	literacy	4	1.3115
15.	modeling	4	1.3115
16.	policy	3	0.9836
17.	education	3	0.9836
18.	structural	3	0.9836
19.	cross	3	0.9836
20.	deliberative	3	0.9836
21.	equation	3	0.9836
22.	conservation	3	0.9836
23.	marketing	2	0.6557
24.	in	2	0.6557
25.	participatory	2	0.6557
26.	globalization	2	0.6557
27.	development	2	0.6557
28.	cultural	2	0.6557
29.	behaviour	2	0.6557
30.	change	2	0.6557
31.	green	2	0.6557
32.	women	2	0.6557
33.	responsible	2	0.6557
34.	measurement	2	0.6557
35.	ecological	2	0.6557
36.	political	2	0.6557
37.	approach	2	0.6557
38.	consumer	2	0.6557
39.	shared	2	0.6557
40.	materialism	2	0.6557
41.	pro	2	0.6557
42.	valuation	2	0.6557
43.	environmentally	2	0.6557
44.	national	2	0.6557
45.	model	2	0.6557
46.	offs	1	0.3279
47.	expression	1	0.3279
48.	planning	1	0.3279
49.	multidimensional	1	0.3279
50.	of	1	0.3279
51.	decision	1	0.3279
52.	to	1	0.3279
53.	sustainability	1	0.3279
54.	culture	1	0.3279
55.	ecocentric	1	0.3279
56.	perceived	1	0.3279
57.	teachers	1	0.3279
58.	learning	1	0.3279
59.	chinese	1	0.3279
60.	leadership	1	0.3279
61.	trust	1	0.3279
62.	sensitivity	1	0.3279

63.	training	1	0.3279
64.	progressive	1	0.3279
65.	developing	1	0.3279
66.	systems	1	0.3279
67.	time	1	0.3279
68.	movements	1	0.3279
69.	orientations	1	0.3279
70.	teacher	1	0.3279
71.	availability	1	0.3279
72.	path	1	0.3279
73.	discount	1	0.3279
74.	activists	1	0.3279
75.	intentions	1	0.3279
76.	multilevel	1	0.3279
77.	survey	1	0.3279
78.	public	1	0.3279
79.	societies	1	0.3279
80.	behaviors	1	0.3279
81.	bayesian	1	0.3279
82.	aposematism	1	0.3279
83.	theory	1	0.3279
84.	economy	1	0.3279
85.	structured	1	0.3279
86.	politics	1	0.3279
87.	ecosystems	1	0.3279
88.	transformation	1	0.3279
89.	cgss	1	0.3279
90.	post	1	0.3279
91.	hypothesis	1	0.3279
92.	willingness	1	0.3279
93.	preferences	1	0.3279
94.	institutional	1	0.3279
95.	responsibility	1	0.3279
96.	climate	1	0.3279
97.	questionnaire	1	0.3279
98.	steep	1	0.3279
99.	making	1	0.3279
100.	capital	1	0.3279
101.	formation	1	0.3279
102.	choice	1	0.3279
103.	general	1	0.3279
104.	transition	1	0.3279
105.	commitment	1	0.3279
106.	biographical	1	0.3279
107.	subjective	1	0.3279
108.	attitude	1	0.3279
109.	maps	1	0.3279
110.	context	1	0.3279
111.	diagram	1	0.3279
112.	colour	1	0.3279
113.	solomon	1	0.3279
114.	world	1	0.3279
115.	comparison	1	0.3279
116.	socialization	1	0.3279
117.	islands	1	0.3279
118.	perspective	1	0.3279
119.	segmentation	1	0.3279
120.	effectiveness	1	0.3279
121.	assessment	1	0.3279
122.	organizing	1	0.3279
123.	rate	1	0.3279
124.	literature	1	0.3279
125.	belief	1	0.3279
126.	mediation	1	0.3279
127.	young	1	0.3279
128.	opportunity	1	0.3279

129.	curriculum	1	0.3279
130.	predictors	1	0.3279
131.	affluence	1	0.3279
132.	society	1	0.3279
133.	consultation	1	0.3279
134.	kuwait	1	0.3279
135.	risk	1	0.3279
136.	and	1	0.3279
137.	recycling	1	0.3279
138.	interest	1	0.3279
139.	perception	1	0.3279
140.	psychometrics	1	0.3279
141.	differences	1	0.3279
142.	regional	1	0.3279
143.	goods	1	0.3279
144.	environmentalism	1	0.3279
145.	individualism	1	0.3279
146.	criteria	1	0.3279
147.	emotions	1	0.3279
148.	norm	1	0.3279
149.	pay	1	0.3279
150.	service	1	0.3279
151.	pre	1	0.3279
152.	price	1	0.3279
153.	attributions	1	0.3279
154.	experiments	1	0.3279
155.	collectivism	1	0.3279
156.	countries	1	0.3279
157.	self	1	0.3279
158.	fair	1	0.3279
159.	comparative	1	0.3279
160.	justice	1	0.3279
161.	assigned	1	0.3279
162.	approaches	1	0.3279
163.	management	1	0.3279
164.	analysis	1	0.3279
165.	china	1	0.3279
166.	people	1	0.3279
167.	trade	1	0.3279
168.	animals	1	0.3279

Appendix C

Bibliographic coupling network


Stern Pc 2000
Dunlap Re 2000
Schultz Pw 2001
Whitman L 2011
Whitman L 2008
Whitman L 2010
Lorenz Dt 2007
Dietz D 2005
Reorting W 2004
Schultz Pw 2005
Oreg S 2006
Lindenberg S 2007
Wilson C 2008
Brown Pa 2008
Kilbourn W 2008
Carrington Mj 2010
Barr S 2007
Knight A 2008
Cowling M 2008
Meyer Dc 2010
Hunter Gl 2004
Hawro J 2010
Franzen A 2010
Clark T 2003
Gabrenya Wk 2003
Abraham W 2007
Harpreet S T 2014
Terhaar Chj 2005
Teppe J 2011
Allan Gt 2010
Gaertner B 2002
Verplanken B 2008
Yukse A 2010
Brown S 2002
Nisbet Ea 2008
Feyrer J 2010
Morrison M 2010
Milton J 2010
Bennett Jc 2008
Moser C 2010
Fleming W 2011
Barnes S 2011
Hadi S 2008
Dietz D 2007
De Groot Im 2007
De Groot Im 2008
Karlen E 2014
Siegel L 2006
Erikson L 2006
Gifford R 2011
Wilson J 2006
Mcdonald Rm 2007
Kim O 2006
Bonell C 2006
Lee C 2006
Siddiqui Rn 2011
Barr 2010
Barr 2006
Barr 2005
Lee 2006
Zhao 2014
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Graeupner M 2013
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Appendix D

LDC CDM Targets
(as per EB-2010-0215/EB-2010-0216, Appendix A)

Appendix A
EB-2010-0215
EB-2010-0216
March 14, 2011

LDC CDM Targets

#	License Name	2014 Net Annual Peak Demand Savings Target (MW)	2011-2014 Net Cumulative Energy Savings Target (GWh)
1	Algoma Power Inc.	1.280	7.370
2	Atikokan Hydro Inc.	0.200	1.160
3	Attawapiskat Power Corporation	0.070	0.290
4	Bluewater Power Distribution Corporation	10.650	53.730
5	Brant County Power Inc.	3.300	9.850
6	Brantford Power Inc.	11.380	48.920
7	Burlington Hydro Inc.	21.950	82.370
8	COLLUS Power Corporation	3.140	14.970
9	Cambridge and North Dumfries Hydro Inc.	17.680	73.660
10	Canadian Niagara Power Inc.	4.070	15.810
11	Canadian Niagara Power Inc. – Port Colborne distribution service territory	2.330	9.270
12	Centre Wellington Hydro Ltd.	1.640	7.810
13	Chapleau Public Utilities Corporation	0.170	1.210
14	Chatham-Kent Hydro Inc.	9.670	37.280
15	Clinton Power Corporation	0.320	1.380
16	Cooperative Hydro Embrun Inc.	0.340	1.120
17	E.L.K. Energy Inc.	2.690	8.250
18	ENWIN Utilities Ltd.	26.810	117.890
19	Enersource Hydro Mississauga Inc.	92.980	417.220
20	Erie Thames Powerlines Corporation	4.280	18.600
21	Espanola Regional Hydro Distribution Corporation	0.520	2.760
22	Essex Powerlines Corporation	7.190	21.540
23	Festival Hydro Inc.	6.230	29.250
24	Fort Albany Power Corporation	0.050	0.240
25	Fort Frances Power Corporation	0.610	3.640
26	Greater Sudbury Hydro Inc.	8.220	43.710
27	Grimsby Power Inc.	2.060	7.760
28	Guelph Hydro Electric Systems Inc.	16.710	79.530
29	Haldimand County Hydro Inc.	2.850	13.300
30	Halton Hills Hydro Inc.	6.150	22.480
31	Hearst Power Distribution Company Limited	0.680	3.910
32	Horizon Utilities Corporation	60.360	281.420
33	Hydro 2000 Inc.	0.190	1.040
34	Hydro Hawkesbury Inc.	1.820	9.280

#	License Name	2014 Net Annual Peak Demand Savings Target (MW)	2011-2014 Net Cumulative Energy Savings Target (GWh)
35	Hydro One Brampton Networks Inc.	45.610	189.540
36	Hydro One Networks Inc.	213.660	1,130.210
37	Hydro Ottawa Limited	85.260	374.730
38	Innisfil Hydro Distribution Systems Limited	2.500	9.200
39	Kashechewan Power Corporation	0.070	0.330
40	Kenora Hydro Electric Corporation Ltd.	0.860	5.220
41	Kingston Hydro Corporation	6.630	37.160
42	Kitchener-Wilmot Hydro Inc.	21.560	90.290
43	Lakefront Utilities Inc.	2.770	13.590
44	Lakeland Power Distribution Ltd.	2.320	10.180
45	London Hydro Inc.	41.440	156.640
46	Middlesex Power Distribution Corporation	2.450	9.250
47	Midland Power Utility Corporation	2.390	10.820
48	Milton Hydro Distribution Inc.	8.050	33.500
49	Newmarket - Tay Power Distribution Ltd.	8.760	33.050
50	Niagara Peninsula Energy Inc.	15.490	58.040
51	Niagara-on-the-Lake Hydro Inc.	2.420	8.270
52	Norfolk Power Distribution Inc.	4.250	15.680
53	North Bay Hydro Distribution Limited	5.050	26.100
54	Northern Ontario Wires Inc.	1.060	5.880
55	Oakville Hydro Electricity Distribution Inc.	20.700	74.060
56	Orangeville Hydro Limited	2.780	11.820
57	Orillia Power Distribution Corporation	3.070	15.050
58	Oshawa PUC Networks Inc.	12.520	52.240
59	Ottawa River Power Corporation	1.610	8.970
60	PUC Distribution Inc.	5.580	30.830
61	Parry Sound Power Corporation	0.740	4.160
62	Peterborough Distribution Incorporated	8.720	38.450
63	Port Colborne Hydro Inc.	0.0	0.0
64	PowerStream Inc.	95.570	407.340
65	Renfrew Hydro Inc.	1.050	4.860
66	Rideau St. Lawrence Distribution Inc.	1.220	5.100
67	Sioux Lookout Hydro Inc.	0.510	3.320
68	St. Thomas Energy Inc.	3.940	14.920
69	Thunder Bay Hydro Electricity Distribution Inc.	8.480	47.380
70	Tillsonburg Hydro Inc.	2.290	10.250
71	Toronto Hydro-Electric System Limited	286.270	1,303.990
72	Veridian Connections Inc.	29.050	115.740
73	Wasaga Distribution Inc.	1.340	4.010
74	Waterloo North Hydro Inc.	15.790	66.490
75	Welland Hydro-Electric System Corp.	5.560	20.600
76	Wellington North Power Inc.	0.930	4.520
77	West Coast Huron Energy Inc.	0.880	8.280

#	License Name	2014 Net Annual Peak Demand Savings Target (MW)	2011-2014 Net Cumulative Energy Savings Target (GWh)
78	West Perth Power Inc.	0.620	2.990
79	Westario Power Inc.	4.240	20.950
80	Whitby Hydro Electric Corporation	10.900	39.070
81	Woodstock Hydro Services Inc.	4.490	18.880
Total		**1,330.04**	**5,999.970**

Appendix E

HLM Models

Program: HLM 7 Hierarchical Linear and Nonlinear Modeling
Authors: Stephen Raudenbush, Tony Bryk, & Richard Congdon
Publisher: Scientific Software International, Inc. (c) 2013
hlm@ssicentral.com
www.ssicentral.com

Module: HLM2S.EXE (7.03.21710.17001)
Date: 23 July 2018, Monday
Time: 13:28:11

Specifications for this HLM2 run

Problem Title: no title

The data source for this run = July23
The command file for this run = C:\Users\steph\AppData\Local\Temp\whlmtemp.hlm
Output file name = C:\Users\steph\Desktop\UWSteph\PhD\Paper 2_OEB analysis (SPSS)\March 2018 Models\hlm2.html
The maximum number of level-1 units = 283
The maximum number of level-2 units = 72
The maximum number of iterations = 100

Method of estimation: full maximum likelihood

The outcome variable is CUMULATI

Summary of the model specified

Level-1 Model

$$CUMULATI_{ti} = \pi_{0i} + e_{ti}$$

Level-2 Model

$$\pi_{0i} = \beta_{00} + r_{0i}$$

Mixed Model

$$CUMULATI_{ti} = \beta_{00} + r_{0i} + e_{ti}$$

Final Results - Iteration 7

Iterations stopped due to small change in likelihood function

σ^2 = 1180.75440

Standard error of σ^2 = 113.87298

τ
INTRCPT1,π_0 135.02871

Standard error of τ
INTRCPT1,π_0 77.33673

Random level-1 coefficient	Reliability estimate
INTRCPT1,π_0	0.313

The value of the log-likelihood function at iteration 7 = -1.434942E+003

Final estimation of fixed effects:

Fixed Effect	Coefficient	Standard error	*t*-ratio	Approx. *d.f.*	*p*-value
For INTRCPT1, π_0					
INTRCPT2, β_{00}	72.775093	2.447598	29.733	71	<0.001

Final estimation of fixed effects (with robust standard errors)

Fixed Effect	Coefficient	Standard error	*t*-ratio	Approx. *d.f.*	*p*-value
For INTRCPT1, π_0					
INTRCPT2, β_{00}	72.775093	2.447583	29.733	71	<0.001

Final estimation of variance components

Random Effect	Standard Deviation	Variance Component	*d.f.*	χ^2	*p*-value
INTRCPT1, r_0	11.62019	135.02871	71	104.69738	0.006
level-1, *e*	34.36211	1180.75440			

Statistics for the current model

Deviance = 2869.883457
Number of estimated parameters = 3

Program: HLM 7 Hierarchical Linear and Nonlinear Modeling
Authors: Stephen Raudenbush, Tony Bryk, & Richard Congdon
Publisher: Scientific Software International, Inc. (c) 2013
hlm@ssicentral.com
www.ssicentral.com

Module: HLM2S.EXE (7.03.21710.17001)
Date: 23 July 2018, Monday
Time: 16: 1:15

Specifications for this HLM2 run

Problem Title: no title

The data source for this run = July23
The command file for this run = C:\Users\steph\AppData\Local\Temp\whlmtemp.hlm
Output file name = C:\Users\steph\Desktop\UWSteph\PhD\Paper 2_OEB analysis (SPSS)\March 2018 Models\hlm2.html
The maximum number of level-1 units = 283
The maximum number of level-2 units = 72
The maximum number of iterations = 100

Method of estimation: full maximum likelihood

The outcome variable is CUMULATI

Summary of the model specified

Level-1 Model

$$CUMULATI_{ti} = \pi_{0i} + \pi_{1i}*(TIME1RE_{ti}) + e_{ti}$$

Level-2 Model

$$\pi_{0i} = \beta_{00} + r_{0i}$$
$$\pi_{1i} = \beta_{10}$$

Mixed Model

$$CUMULATI_{ti} = \beta_{00} + \beta_{10}*TIME1RE_{ti} + r_{0i} + e_{ti}$$

Final Results - Iteration 3

Iterations stopped due to small change in likelihood function

σ^2 = 190.20445

Standard error of σ^2 = 18.34489

τ
INTRCPT1,π_0 380.68662

Standard error of τ
INTRCPT1,π_0 71.55612

Random level-1 coefficient	Reliability estimate
INTRCPT1,π_0	0.889

The value of the log-likelihood function at iteration 3 = -1.238416E+003

Final estimation of fixed effects:

Fixed Effect	Coefficient	Standard error	*t*-ratio	Approx. *d.f.*	*p*-value
For INTRCPT1, π_0					
INTRCPT2, β_{00}	109.283636	2.671722	40.904	71	<0.001
For TIME1RE slope, π_1					
INTRCPT2, β_{10}	97.732373	2.919255	33.479	214	<0.001

Final estimation of fixed effects
(with robust standard errors)

Fixed Effect	Coefficient	Standard error	*t*-ratio	Approx. *d.f.*	*p*-value
For INTRCPT1, π_0					
INTRCPT2, β_{00}	109.283636	3.696465	29.564	71	<0.001
For TIME1RE slope, π_1					
INTRCPT2, β_{10}	97.732373	4.176432	23.401	214	<0.001

Final estimation of variance components

Random Effect	Standard Deviation	Variance Component	*d.f.*	χ^2	*p*-value
INTRCPT1, r_0	19.51119	380.68662	71	648.10123	<0.001
level-1, e	13.79146	190.20445			

Statistics for the current model

Deviance = 2476.832276
Number of estimated parameters = 4

Model comparison test

χ^2 statistic = 115.84983
Degrees of freedom = 0
p-value = >.500

Program: HLM 7 Hierarchical Linear and Nonlinear Modeling
Authors: Stephen Raudenbush, Tony Bryk, & Richard Congdon
Publisher: Scientific Software International, Inc. (c) 2013
hlm@ssicentral.com
www.ssicentral.com

Module: HLM2S.EXE (7.03.21710.17001)
Date: 23 July 2018, Monday
Time: 16: 1:59

Specifications for this HLM2 run

Problem Title: no title

The data source for this run = July23
The command file for this run = C:\Users\steph\AppData\Local\Temp\whlmtemp.hlm
Output file name = C:\Users\steph\Desktop\UWSteph\PhD\Paper 2_OEB analysis (SPSS)\March 2018 Models\hlm2.html
The maximum number of level-1 units = 283
The maximum number of level-2 units = 72
The maximum number of iterations = 100

Method of estimation: full maximum likelihood

The outcome variable is CUMULATI

Summary of the model specified

Level-1 Model

$$CUMULATI_{ti} = \pi_{0i} + \pi_{1i}*(TIME1RE_{ti}) + e_{ti}$$

Level-2 Model

$$\pi_{0i} = \beta_{00} + r_{0i}$$
$$\pi_{1i} = \beta_{10} + r_{1i}$$

Mixed Model

$$CUMULATI_{ti} = \beta_{00} + \beta_{10}*TIME1RE_{ti} + r_{0i} + r_{1i}*TIME1RE_{ti} + e_{ti}$$

Final Results - Iteration 7

Iterations stopped due to small change in likelihood function

$\sigma^2 = 90.86785$

Standard error of $\sigma^2 = 10.73604$

τ

INTRCPT1,π_0	918.14687	861.79772
TIME1RE,π_1	861.79772	950.31124

Standard errors of τ

INTRCPT1,π_0	163.81186	173.87909
TIME1RE,π_1	173.87909	210.14739

τ (as correlations)

INTRCPT1,π_0	1.000	0.923
TIME1RE,π_1	0.923	1.000

Random level-1 coefficient	Reliability estimate
INTRCPT1,π_0	0.935
TIME1RE,π_1	0.763

The value of the log-likelihood function at iteration 7 = -1.187542E+003

Final estimation of fixed effects:

Fixed Effect	Coefficient	Standard error	*t*-ratio	Approx. *d.f.*	*p*-value
For INTRCPT1, π_0					
INTRCPT2, β_{00}	109.282322	3.692790	29.593	71	<0.001
For TIME1RE slope, π_1					
INTRCPT2, β_{10}	97.724486	4.156680	23.510	71	<0.001

Final estimation of fixed effects
(with robust standard errors)

Fixed Effect	Coefficient	Standard error	*t*-ratio	Approx. *d.f.*	*p*-value
For INTRCPT1, π_0					
INTRCPT2, β_{00}	109.282322	3.692773	29.594	71	<0.001
For TIME1RE slope, π_1					
INTRCPT2, β_{10}	97.724486	4.156613	23.511	71	<0.001

Final estimation of variance components

Random Effect	Standard Deviation	Variance Component	*d.f.*	χ^2	*p*-value

INTRCPT1, r_0	30.30094	918.14687	71	1111.18728	<0.001
TIME1RE slope, r_1	30.82712	950.31124	71	306.58353	<0.001
level-1, e	9.53246	90.86785			

Statistics for the current model

Deviance = 2375.084450
Number of estimated parameters = 6

Model comparison test

χ^2 statistic = 101.74783
Degrees of freedom = 2
p-value = <0.001

Program: HLM 7 Hierarchical Linear and Nonlinear Modeling
Authors: Stephen Raudenbush, Tony Bryk, & Richard Congdon
Publisher: Scientific Software International, Inc. (c) 2013
hlm@ssicentral.com
www.ssicentral.com

Module: HLM2S.EXE (7.03.21710.17001)
Date: 23 July 2018, Monday
Time: 16: 2:55

Specifications for this HLM2 run

Problem Title: no title

The data source for this run = July23
The command file for this run = C:\Users\steph\AppData\Local\Temp\whlmtemp.hlm
Output file name = C:\Users\steph\Desktop\UWSteph\PhD\Paper 2_OEB analysis (SPSS)\March 2018 Models\hlm2.html
The maximum number of level-1 units = 283
The maximum number of level-2 units = 72
The maximum number of iterations = 100

Method of estimation: full maximum likelihood

The outcome variable is CUMULATI

Summary of the model specified

Level-1 Model

$$CUMULATI_{ti} = \pi_{0i} + \pi_{1i}*(TIME1RE_{ti}) + e_{ti}$$

Level-2 Model

$$\pi_{0i} = \beta_{00} + \beta_{01}*(ZCUSTDM_i) + r_{0i}$$
$$\pi_{1i} = \beta_{10} + r_{1i}$$

ZCUSTDM has been centered around the grand mean.

Mixed Model

$$CUMULATI_{ti} = \beta_{00} + \beta_{01}*ZCUSTDM_i + \beta_{10}*TIME1RE_{ti} + r_{0i} + r_{1i}*TIME1RE_{ti} + e_{ti}$$

Final Results - Iteration 7

Iterations stopped due to small change in likelihood function

σ^2 = 90.87227

Standard error of σ^2 = 10.73643

τ

INTRCPT1,π_0	869.59115	840.88478
TIME1RE,π_1	840.88478	950.31643

Standard errors of τ

INTRCPT1,π_0	155.72865	169.81432
TIME1RE,π_1	169.81432	210.14757

τ (as correlations)

INTRCPT1,π_0	1.000	0.925
TIME1RE,π_1	0.925	1.000

Random level-1 coefficient	Reliability estimate
INTRCPT1,π_0	0.932
TIME1RE,π_1	0.763

The value of the log-likelihood function at iteration 7 = -1.184829E+003

Final estimation of fixed effects:

Fixed Effect	Coefficient	Standard error	*t*-ratio	Approx. *d.f.*	*p*-value
For INTRCPT1, π_0					
INTRCPT2, β_{00}	109.279481	3.600223	30.354	70	<0.001
ZCUSTDM, β_{01}	4.073135	1.696878	2.400	70	0.019
For TIME1RE slope, π_1					
INTRCPT2, β_{10}	97.707441	4.156608	23.507	71	<0.001

Final estimation of fixed effects
(with robust standard errors)

Fixed Effect	Coefficient	Standard error	*t*-ratio	Approx. *d.f.*	*p*-value
For INTRCPT1, π_0					
INTRCPT2, β_{00}	109.279481	3.600443	30.352	70	<0.001
ZCUSTDM, β_{01}	4.073135	1.355652	3.005	70	0.004
For TIME1RE slope, π_1					
INTRCPT2, β_{10}	97.707441	4.156815	23.505	71	<0.001

Final estimation of variance components

Random Effect	Standard Deviation	Variance Component	*d.f.*	χ^2	*p*-value
INTRCPT1, r_0	29.48883	869.59115	70	1056.13024	<0.001
TIME1RE slope, r_1	30.82720	950.31643	71	306.56876	<0.001
level-1, *e*	9.53269	90.87227			

Statistics for the current model

Deviance = 2369.657077
Number of estimated parameters = 7

Model comparison test

χ^2 statistic = 5.42737
Degrees of freedom = 1
p-value = 0.019

Program: HLM 7 Hierarchical Linear and Nonlinear Modeling
Authors: Stephen Raudenbush, Tony Bryk, & Richard Congdon
Publisher: Scientific Software International, Inc. (c) 2013
hlm@ssicentral.com
www.ssicentral.com

Module: HLM2S.EXE (7.03.21710.17001)
Date: 23 July 2018, Monday
Time: 16: 3:49

Specifications for this HLM2 run

Problem Title: no title

The data source for this run = July23
The command file for this run = C:\Users\steph\AppData\Local\Temp\whlmtemp.hlm
Output file name = C:\Users\steph\Desktop\UWSteph\PhD\Paper 2_OEB analysis (SPSS)\March 2018 Models\hlm2.html
The maximum number of level-1 units = 283
The maximum number of level-2 units = 72
The maximum number of iterations = 100

Method of estimation: restricted maximum likelihood

The outcome variable is CUMULATI

Summary of the model specified

Level-1 Model

$$CUMULATI_{ti} = \pi_{0i} + \pi_{1i}*(TIME1RE_{ti}) + e_{ti}$$

Level-2 Model

$$\pi_{0i} = \beta_{00} + \beta_{01}*(ZCUSTDM_i) + r_{0i}$$
$$\pi_{1i} = \beta_{10} + r_{1i}$$

ZCUSTDM has been centered around the grand mean.

Mixed Model

$$CUMULATI_{ti} = \beta_{00} + \beta_{01}*ZCUSTDM_i + \beta_{10}*TIME1RE_{ti} + r_{0i} + r_{1i}*TIME1RE_{ti} + e_{ti}$$

Final Results - Iteration 16

Iterations stopped due to small change in likelihood function

$\sigma^2 = 90.88058$

τ

INTRCPT1,π_0	885.72283	854.25199
TIME1RE,π_1	854.25199	967.74391

τ (as correlations)

INTRCPT1,π_0	1.000	0.923
TIME1RE,π_1	0.923	1.000

Random level-1 coefficient	Reliability estimate
INTRCPT1,π_0	0.933
TIME1RE,π_1	0.766

The value of the log-likelihood function at iteration 16 = -1.180491E+003

Final estimation of fixed effects:

Fixed Effect	Coefficient	Standard error	*t*-ratio	Approx. *d.f.*	*p*-value
For INTRCPT1, π_0					
INTRCPT2, β_{00}	109.279547	3.631296	30.094	70	<0.001
ZCUSTDM, β_{01}	4.072866	1.720920	2.367	70	0.021
For TIME1RE slope, π_1					
INTRCPT2, β_{10}	97.707840	4.185754	23.343	71	<0.001

Final estimation of fixed effects (with robust standard errors)

Fixed Effect	Coefficient	Standard error	*t*-ratio	Approx. *d.f.*	*p*-value
For INTRCPT1, π_0					
INTRCPT2, β_{00}	109.279547	3.600452	30.352	70	<0.001
ZCUSTDM, β_{01}	4.072866	1.355638	3.004	70	0.004
For TIME1RE slope, π_1					
INTRCPT2, β_{10}	97.707840	4.156787	23.506	71	<0.001

Final estimation of variance components

Random Effect	Standard Deviation	Variance Component	*d.f.*	χ^2	*p*-value
INTRCPT1, r_0	29.76110	885.72283	70	1056.03611	<0.001
TIME1RE slope, r_1	31.10858	967.74391	71	306.54073	<0.001

	level-1, e	9.53313	90.88058

Statistics for current covariance components model

Deviance = 2360.982445
Number of estimated parameters = 4

Variance-Covariance components test

χ^2 statistic = 14.10200
Degrees of freedom = 2
p-value = 0.001

Appendix F

Analysis Tracking sheet

CUMULATIVE	**Model 1**	**Model 2**	**Model 3**	**Model 4**	**Model 5**
Level	Null	Level 1	Level 1	Level 2	Level 2
Title	Base model (full maximum likelihood)	One-way ANCOVA with random effects	Random-coefficient	Level 2 predictors	Restricted maximum likelihood of final model
Notes		add time (predictor variable) uncentered at level 1, with random effect at intercept	*add quadtime and cost_cust (predictor variables) uncentered at level 1; no random effects at level 2 intercepts* *model fit did not improve, therefore quadtime was deleted* random coefficient for time added	added Cust_Den at intercept at Level 2,with random effects; *added all other predictors at all levels, using correlation matrix as guide; no other significant effects*	
MDM file name	July 23 model.hlm	July 23 model.hlm	July 23 model.hlm	July 23 model.hlm	July 23 model.hlm
MDMT name	July23.mdmt	July23.mdmt	July23.mdmt	July23.mdmt	July23.mdmt
Level 1 Model	$CUMULATI_{ti} = \pi_{0i} + e_{ti}$	*CUMULATIti = π0i + π1i*(TIME1REti) + eti*	CUMULATIti = π0i + π1i*(TIME1REti) + eti	CUMULATIti = π0i + π1i*(TIME1REti) + eti	CUMULATIti = π0i + π1i*(TIME1REti) + eti
Level 2 Model	π0i = β00 + r0i	*π0i = β00 + r0i* π1i = β10	π0i = β00 + r0i π1i = β10 + r1i	π0i = β00 + β01*(ZCUSTDMi) + r0i π1i = β10 + r1i	π0i = β00 + β01*(ZCUSTDMi) + r0i π1i = β10 + r1i
Mixed Model	CUMULATIti = β00 + r0i+ eti	*CUMULATIti = β00* + β 10*TIME1REti + r0i+ eti	CUMULATIti = β00 + β10*TIME1REti + r0i + r1i*(TIME1REti) + eti	CUMULATIti = β00 + β01*(ZCUSTDMi) + β10*TIME1REti + r0i + r1i*TIME1REti + eti	CUMULATIti = β00 + β01*(ZCUSTDMi) + β10*TIME1REti + r0i + r1i*TIME1REti + eti
FIXED EFFECTS					
Intercept					
Intercept	**72.775093 (2.447583)**	**109.283636 (3.696465)**	**109.282322 (3.692773)**	**109.279481(3.60043)**	**109.279547(3.600452)**
ZCustDM				**4.073135 (1.355652)**	**4.072866 (1.355638)**
Slope (Time1)					
Intercept		**97.732373 (4.176432)**	**97.724486 (4.156613)**	**97.707441(4.156815)**	**97.707840(4.156787)**
ZCustDM				N/A	N/A
VARIANCE COMPONENTS					
Level-1	1180.7544	190.20445	90.86785	90.87227	90.88058
Intercept	**135.02871**	**380.68662**	**918.14687**	**869.59115**	**885.72283**
Time1 Slope			**950.31124**	**950.31643**	**967.74391**
Deviance	2869.883457	2476.832276	2375.08445	2369.657077	2360.982445
# of parameters	3	4	6	7	4
Model Comparison		$X^2(1) = 393.05118$, p <.001	$X^2(2) = 101.74783$, p <.001	$X^2(1) = 5.42737$, p = 0.019	$X^2(2) = 14.10200$, p<.001
ICC	10.26%	66.68%	90.99%	90.54%	90.69%
VARIANCE EXPLAINED					
Level-1	NULL	84%	92%	92%	92.30%
Intercept				5%	3.53%
Time Slope					
Cust_Den					
Reliability					
Intercept	0.313	0.889	0.935	0.932	0.933
Time Slope			0.763	0.763	0.766

Appendix G

Interview Protocol

INTERVIEW PROTOCOL – BUILDING OWNERS AND MANAGERS

Introductory script

Hello! My name is Stephanie Whitney, I'm a PhD candidate from the University of Waterloo. This study is part of my PhD thesis at UW – I am supervised by Profs. Jennifer Lynes and Ian Rowlands – and also part of a broader research project being led by Prof. Manuel Riemer at Wilfrid Laurier University. I'm here to learn about motivations and barriers of building owners and managers to engaging in sustainability practices within commercial office buildings. Thank you for taking the time to talk with me today. Have you had a chance to read the informed consent letter that was sent to you? Do have you have any questions about the consent letter or about the study in general? *[Answer any questions before proceeding.]* I want to emphasize a few points from the consent letter: There are no right or wrong answers, or desirable or undesirable answers. I would like you to feel comfortable saying what you really think and how you really feel. Also, if it's okay with you, I will be tape-recording our conversation since it is hard for me to write down everything while simultaneously carrying an attentive conversation with you. If at any time you would like to say something "off the record", please let me know and I will turn the recorder off during that time. Everything you say will remain confidential, meaning that only I and my research team will be able to identify your answers, so we know whom to contact should we have further follow-up questions after this interview. When this information is shared, all potentially identifying information has been removed. You will have a chance to review any quotes from your interview that we are planning to use before we will include them in any published report. Do I have your permission to proceed?

[*Turn on the recorder and state interviewee ID, date, and start time*]

Interview Questions and Prompts

We will start with a few questions about your background.

1. **What is your job title?**

2. **How long have you worked for [name of the organization]?**

Script: Sounds like you must have a wealth of experience and knowledge about commercial buildings! My experiences with commercial buildings have been mostly as an occupant, or a visitor. I'm really interested in understanding your perspective as a building manager. To that end…

3. **I'd like you to help me understand the roles and responsibilities of a building manager. Tell me about the key aspects of your job.**

PROMPTS:

a. *Building Infrastructure/assets*: Purchase, rebuild, retrofit, sell – how often?
b. *Operations*: Managed directly or contracted? Management system to monitor/track/report?

BO	• Energy: Preventative maintenance, ASHRAE Assessment, Mgmt Plan, reduction target plan

	• Water: Assessment, Mgmt Plan (including conservation measures)
	• Air: HVAC and IAQ monitoring
	• Comfort: Occupant service request program
	• Health & Wellness: Hazardous Building Materials & Chemical Products Mgmt Programs
	• Custodial: Green cleaning program
	• Waste: Source separation, waste audit, waste reduction workplan
	• Engagement: Overarching env'tal policy, occupant env'tal communication program

c. *Engagement*: Communication with tenants? Other stakeholders? Describe nature of relationships.

4. In regard to the different aspects you described, what are the key decision-making criteria?

PROMPTS:

a. Regulations: Compliance with mandatory or voluntary standards, industry best practices
b. *Financial*: ROI threshold, CAPP Rate, etc.
c. *CSR*: corporate mission, values, social license
d. *Risk assessment and mitigation*: climate change, insurance
e. *Relationships*: deep commitment to tenants
f. *Sustainability: how does the participant define this?*
g. *Other*?

5. What about (an aspect and/or criteria listed above)? Is that a decision-making criteria?

PROMPTS:

a. Consider the 'missed' aspect as part of another aspect
b. Not critical to the management of property assets
c. No business case

6. In the last five years, have you made any investments or implemented specific activities that have the potential to reduce the environmental impact of your assets? If so, what motivated those investments?

PROMPTS:

a. Low-hanging fruit – short ROI (lights, motion sensors)
b. Showcase examples – more expensive, but stakeholders were engaged (green living wall)
c. Clear business case for larger projects – e.g. combined systems for resources/services
d. Utilized regional/provincial/federal incentives (roving energy manager)

7. Have you considered other investments or activities focused on reducing the environmental impact of your assets that you ultimately did not implement? Please elaborate.

8. **The ultimate purpose of this work is to engage people like you, building managers, to consider sustainability more integrally in decision-making regarding all aspects of building management. I would like you to switch from being my interviewee to being my consultant right now.**

    a. **First, I would like to ask you how people in your positions understand sustainability, especially in reference to office buildings?**
    b. **Second, what would be your approach to engaging somebody in your position to consider sustainability? What benefits would you promote, what barriers would you try to remove, etc. to move this forward? How would you make the business case for sustainability?**
    c. **Third, if you would be asked to make an assessment of whether there is a "culture of sustainability" (COS) present in an office building, what would you be looking for?**
    d. **Finally, do you think there is a role for building managers in promoting a culture of sustainability in the buildings they manage? If so, what would that role be?**

PROMPTS:
A COS is characterized by shared values, norms, language, and practices focused on making individual and societal choices that foster social, economic and environmental sustainability.

9. **This brings us to the end of our interview. Before I turn off the recorder, can you think of anything else that we did not cover in our conversation that would be valuable for me to know?**

Ok, this concludes our interview then. Thank you so much for making this time and serving as a key informant and as my consultant. Once we have finished the interviews and analyzed them we will be in touch with you if there are any specific quotes we would like to use from your interview. I will now turn off the recorder.

[*Record end time and turn off the recorder*]

INTERVIEW PROTOCOL – BUILDING OPERATORS

Introductory script

Hello! My name is Stephanie Whitney, I'm a PhD candidate from the University of Waterloo. This study is part of my PhD thesis at UW – I am supervised by Profs. Jennifer Lynes and Ian Rowlands – and also part of a broader research project being led by Prof. Manuel Riemer at Wilfrid Laurier University. I'm here to learn about motivations and barriers of building owners and managers to engaging in sustainability practices within commercial office buildings. Thank you for taking the time to talk with me today. Have you had a chance to read the informed consent letter that was sent to you? Do have you have any questions about the consent letter or about the study in general? *[Answer any questions before proceeding.]* I want to emphasize a few points from the consent letter: There are no right or wrong answers, or desirable or undesirable answers. I would like you to feel comfortable saying what you really think and how you really feel. Also, if it's okay with you, I will be tape-recording our conversation since it is hard for me to write down everything while simultaneously carrying an attentive conversation with you. If at any time you would like to say something "off the record", please let me know and I will turn the recorder off during that time. Everything you say will remain confidential, meaning that only I and my research team will be able to identify your answers, so we know whom to contact should we have further follow-up questions after this interview. When this information is shared, all potentially identifying information has been removed. You will have a chance to review any quotes from your interview that we are planning to use before we will include them in any published report. Do I have your permission to proceed?

[*Turn on the recorder and state interviewee ID, date, and start time*]

Interview Questions and Prompts

We will start with a few questions about your background.

1. **What is your job title?**
2. **How long have you worked for [name of the organization]?**

Script: Sounds like, you must have a wealth of experience and knowledge about commercial buildings! My experiences with commercial buildings have been mostly as an occupant, or a visitor. I'm really interested in understanding your perspective as a building operator. To that end…

3. **I'd like you to help me understand the roles and responsibilities of a building operator. Tell me about the key aspects of your job.**

PROMPTS:

a. *Building Infrastructure/assets*: Features (age, location, etc.) that influence O&M?
b. *Operations*: Contracted by the owner? Management system to monitor/track/report?

BOM	• Energy: Preventative maintenance, ASHRAE Assessment, Mgmt Plan, reduction target plan
	• Water: Assessment, Mgmt Plan (including conservation measures)

	• Air: HVAC and IAQ monitoring
	• Comfort: Occupant service request program
	• Health & Wellness: Hazardous Building Materials & Chemical Products Mgmt Programs
	• Custodial: Green cleaning program
	• Waste: Source separation, waste audit, waste reduction workplan
	• Engagement: Overarching env'tal policy, occupant env'tal communication program

c. *Engagement*: Communication with tenants? Other stakeholders? Describe nature of relationships.

4. For each of the aspects you described, what are the key decision-making criteria?

PROMPTS:

a. Direction from building owner – what tone with respect to sustainability?
b. Building features influence O&M (age, location, etc.)?
c. Extent to which O&M is corrective vs. preventative
d. Regulations: Compliance with mandatory or voluntary standards, industry best practices
e. *Financial*: ROI threshold, size of operating budget
f. *CSR*: corporate mission, values, social license
g. *Risk assessment and mitigation*: climate change, insurance
h. *Relationships*: deep commitment to tenants
i. *Sustainability: how does the participant define this?*
j. *Other*?

5. What about (an aspect and/or criteria listed above)? Is that a decision-making criteria?

PROMPTS:

a. Consider the 'missed' aspect as part of another aspect
b. Not critical to the management of property assets
c. No business case

6. In the last five years, have you made any investments or implemented specific activities that have the potential to reduce the environmental impact of your assets (operated)? If so, what motivated those investments?

PROMPTS:

a. Low-hanging fruit – short ROI (lights, motion sensors)
b. Direction from building owner/manager
c. Utilized regional/provincial/federal incentives (roving energy manager)
d. Clear business case for larger projects – e.g. combined systems for resources/services

7. Have you considered other sustainability projects that you ultimately did not implement?

8. **The ultimate purpose of this work is to engage people like you, building operators, to consider sustainability more integrally in decision-making regarding all aspects of building operation. I would like you to switch from being my interviewee to being my consultant right now.**

    a. **First, I would like to ask you how people in your positions understand sustainability, especially in reference to office buildings?**
    b. **Second, what would be your approach to engaging somebody in your position to consider sustainability? What benefits would you promote, what barriers would you try to remove, etc. to move this forward? How would you make the business case for sustainability?**
    c. **Third, if you would be asked to make an assessment of whether there is a "culture of sustainability" present in an office building, what would you be looking for?**
    d. **Finally, do you think there is a role for building operators in promoting a culture of sustainability in the buildings they manage? If so, what would that role be?**

PROMPTS:
A COS is characterized by shared values, norms, language, and practices focused on making individual and societal choices that foster social, economic and environmental sustainability.

9. **This brings us to the end of our interview. Before I turn off the recorder, can you think of anything else that we did not cover in our conversation that would be valuable for me to know?**

Ok, this concludes our interview then. Thank you so much for making this time and serving as a key informant and as my consultant. Once we have finished the interviews and analyzed them we will be in touch with you if there are any specific quotes we would like to use from your interview. I will now turn off the recorder.

INTERVIEW PROTOCOL – BUILDING TENANTS

Introductory script

Hello! My name is Stephanie Whitney, I'm a PhD candidate from the University of Waterloo. This study is part of my PhD thesis at UW – I am supervised by Profs. Jennifer Lynes and Ian Rowlands – and also part of a broader research project being led by Prof. Manuel Riemer at Wilfrid Laurier University. I'm here to learn about motivations and barriers of building owners and managers to engaging in sustainability practices within commercial office buildings. Thank you for taking the time to talk with me today. Have you had a chance to read the informed consent letter that was sent to you? Do have you have any questions about the consent letter or about the study in general? *[Answer any questions before proceeding.]* I want to emphasize a few points from the consent letter: There are no right or wrong answers, or desirable or undesirable answers. I would like you to feel comfortable saying what you really think and how you really feel. Also, if it's okay with you, I will be tape-recording our conversation since it is hard for me to write down everything while simultaneously carrying an attentive conversation with you. If at any time you would like to say something "off the record", please let me know and I will turn the recorder off during that time. Everything you say will remain confidential, meaning that only I and my research team will be able to identify your answers, so we know whom to contact should we have further follow-up questions after this interview. When this information is shared, all potentially identifying information has been removed. You will have a chance to review any quotes from your interview that we are planning to use before we will include them in any published report. Do I have your permission to proceed?

[*Turn on the recorder and state interviewee ID, date, and start time*]

Interview Questions and Prompts

We will start with a few questions about your background.

1. **What is your job title?**
2. **How long have you worked for [name of the organization]?**

Script: Sounds like, you must have a wealth of experience and knowledge about commercial buildings! My experiences with commercial buildings have been mostly as an occupant, or a visitor. I'm really interested in understanding your perspective as a building tenant. To that end…

3. **I'd like you to help me understand building occupancy from a tenant's perspective. Tell me about the key aspects of building occupancy/tenancy.**

PROMPTS:

a. *Building Infrastructure/assets*: Decision to rent a space; core purpose of the space – do clients visit
b. *Operations*: Do you pay your own energy and utility bills? Is your unit metered separately?

BOM	• Energy: Preventative maintenance, ASHRAE Assessment, Mgmt Plan, reduction target plan
	• Water: Assessment, Mgmt Plan (including conservation measures)

	• Air: HVAC and IAQ monitoring
	• Comfort: Occupant service request program
	• Health & Wellness: Hazardous Building Materials & Chemical Products Mgmt Programs
	• Custodial: Green cleaning program
	• Waste: Source separation, waste audit, waste reduction workplan
	• Engagement: Overarching env'tal policy, occupant env'tal communication program

c. *Engagement*: Communication with owner and operator? Other tenants? Other stakeholders? Describe nature of relationships.

4. For each of the aspects you described, what are the key decision-making criteria?

PROMPTS:

a. Decision to lease: property class, price, location, lease term, leasehold improvements, services
b. Lease agreement/conditions – any mention of energy efficiency?
c. Regulations: Compliance with mandatory or voluntary standards, industry best practices
d. *Financial*: Cost savings (if pay own bills)
e. *CSR*: corporate mission, values, social license
f. *Risk assessment and mitigation*: climate change, insurance
g. *Relationships*: deep commitment to employees; talent attraction/retention
h. *Sustainability: how does the participant define this?*
i. *Other*?

5. What about (an aspect and/or criteria listed above)? Is that a decision-making criteria?

PROMPTS:

a. Consider the 'missed' aspect as part of another aspect
b. Not critical to the management of property assets
c. No business case

6. In the last five years, have you made any investments or implemented specific activities that have the potential to reduce the environmental impact of your leased space? If so, what motivated those investments or projects?

PROMPTS:

a. Low-hanging fruit – short ROI (lights, motion sensor)
b. Direction from building owner/manager or operator – part of lease agreement or not
c. Utilized regional/provincial/federal incentives (roving energy manager)
d. Initiated by employees, green team or not (kitchen compost)
e. Client-driven

7. **Have you considered other sustainability projects that you ultimately did not implement?**

8. **The ultimate purpose of this work is to engage people like you, building tenants, to consider sustainability more integrally in decision-making regarding all aspects of building occupancy/tenancy. I would like you to switch from being my interviewee to being my consultant right now.**

    a. **First, I would like to ask you how people in your positions understand sustainability, especially in reference to office buildings?**
    b. **Second, what would be your approach to engaging somebody in your position to consider sustainability? What benefits would you promote, what barriers would you try to remove, etc. to move this forward? How would you make the business case for sustainability?**
    c. **Third, if you would be asked to make an assessment of whether there is a "culture of sustainability" present in an office building, what would you be looking for?**
    d. **Finally, do you think there is a role for building managers in promoting a culture of sustainability in the buildings they manage? If so, what would that role be?**

PROMPTS:
A COS is characterized by shared values, norms, language, and practices focused on making individual and societal choices that foster social, economic and environmental sustainability.

9. **This brings us to the end of our interview. Before I turn off the recorder, can you think of anything else that we did not cover in our conversation that would be valuable for me to know?**

Ok, this concludes our interview then. Thank you so much for making this time and serving as a key informant and as my consultant. Once we have finished the interviews and analyzed them we will be in touch with you if there are any specific quotes we would like to use from your interview. I will now turn off the recorder.

Appendix H

Recruitment Materials

WILFRID LAURIER UNIVERSITY (REB#4896)
UNIVERSITY OF WATERLOO (ORE#21928)
INFORMED CONSENT STATEMENT

Fostering sustainable behaviors in an iconic green office building

Dr. Manuel Riemer
Department of Psychology
Stephanie Whitney, PhD Candidate
School of Environment, Resources and Sustainability

Interview with Building Manager/Sustainability Coordinator/Operator/Tenant

You are invited to participate in a research study. The purpose of this study is to learn about the motivations and barriers of private and public sector building managers (that may or may not own the property) to engaging in sustainability practices within commercial office buildings. This study recognizes that there are similarities and differences in motivations and barriers that arise from these two contexts. For example, there are unique opportunities and challenges with respect to energy management in public sector buildings such as (but not limited to) taxpayer expectations for levels of service in community spaces. This study also aims to learn about the individual factors and contextual factors that influence sustainable practices with respect to property management, and aims to develop practical guidelines and tools that building managers can use to engage their tenants in sustainability initiatives, for mutual benefit. This research is being undertaken in partnership with BOMA Canada, and will help us understand the management practices that foster sustainable practices in office buildings. Additionally, this research will be used to develop resources that support building managers in their tenant engagement, in order to move their managed property assets forward with respect to sustainability.

INFORMATION

If you choose to participate, you will be asked to take part in one 60-minute (or shorter) interview. The interview discussion will be audio recorded. During the interview you will be asked to discuss your notions of sustainability and sustainable practices in your workplace and/or buildings you manage, and your general reactions and attitudes towards the persistent performance gap within commercial office buildings, and your motivations and barriers for engaging in sustainability within your roles and responsibilities. We are recruiting 10 building property managers with representation from both the private and public sector (that may also own the managed property) to participate in individual interviews. The interviews will be conducted by Stephanie Whitney, a graduate student at the University of Waterloo, and/or Dr. Manuel Riemer, an Associate Professor at Wilfrid Laurier University. This study is part of the PhD thesis of Stephanie Whitney, who is supervised by Profs. Jennifer Lynes and Ian Rowlands, at the University of Waterloo. This study is also part of a broader research project on the performance gap in commercial office buildings, being led by Prof. Manuel Riemer at Wilfrid Laurier University.

RISKS
There are only minimal risks involved in this study. However, because some aspects of the research ask you to evaluate and reflect on your own thoughts and practices, you may experience some negative emotions. These feelings are normal and should be temporary. We assure you that this study is not intended to evaluate your performance as a building manager (or a member of BOMA Canada). BOMA Canada will not have access to your transcribed interview notes. Instead, they will receive an aggregated and de-identified report, summarizing the findings of this research.

There is some risk to your professional reputation, if somehow your identity is discovered, and if those reading the report have differing opinions on the subject matter. The questions have been designed to focus mainly on your general reactions and attitudes towards various aspects of sustainable behaviour, and your motivations and barriers in the context of your roles and responsibilities, at work. Our report of findings will be anonymous (please see the section on Confidentiality, below).

If you experience any negative feelings as a result of participating in this study, please contact the researchers.

BENEFITS
By participating in this study you will be helping BOMA Canada and the research teams at Wilfrid Laurier University and the University of Wateroo learn about the motivations and barriers that promote or inhibit building managers from engaging with their tenants in sustainability practices, and to identify strategies to support building managers in the movement towards great sustainability in commercial office buildings. This has positive implications for the commercial real estate sector, more broadly. You will also contribute to the academic literature about how to engage stakeholders in sustainability practices .

CONFIDENTIALITY
Only Dr. Manuel Riemer and his research team (Stephanie Whitney, Devon Fernandes, Brandon Hayes, and Bianca Dreyer) will have access to the data. Any hardcopy data, such as written notes, will be stored in a locked cabinet. The audio file will be saved on a password-protected computer and transcribed for analysis by the researchers. The audio files will be deleted once the de-identified transcripts are completed. No personally identifying information (e.g., your name, your contact information) will be stored with your transcribed data. Only your ID code and/or pseudonym will be used to identify your data. The spreadsheet linking your ID to your own name, as well as the electronic copies of the consent forms, will be saved on Dr. Manuel Riemer's password- protected computer in a locked office at WLU, and Stephanie Whitney's password-protected computer in a locked office at UW, and will be destroyed by April 30th, 2018. The de-identified data will be kept for a minimum of seven years, and may be reanalyzed as part of a separate project (i.e., secondary data analysis). We might use direct quotations from you in reports, publications, and presentations. We will take steps to ensure that the quotations cannot be linked to you personally. Your organization will not be named, and any attribution will be at the level of "a building manager in private or public sector commercial building. You will be asked at the end of this form to indicate your consent for the use of your quotations in research publications (i.e., quotes may be used in any way or you would like to review the quotes

before they are used). If you are not willing to be quoted please do not sign this form and/or participate in the focus group.

CONTACT

If you have questions at any time about the study or the procedures, or you experience adverse effects as a result of participating in this study, you may contact Dr. Manuel Riemer at mriemer@wlu.ca or (519) 884-0710, ext. 2982. This project has been reviewed and approved by the University Research Ethics Board (REB #4896), which is supported by the Research Support Fund. If you feel you have not been treated according to the descriptions in this form, or your rights as a participant in research have been violated during the course of this project, you may contact Dr. Robert Basso, Chair, University Research Ethics Board, Wilfrid Laurier University, (519) 884-0710, ext. 4994 or rbasso@wlu.ca.

This study has also been reviewed and received ethics clearance through a University of Waterloo Research Ethics Committee (ORE#21928). If you have questions for the Committee contact the Chief Ethics Officer, Office of Research Ethics, at 1-519-888-4567 ext. 36005 or ore-ceo@uwaterloo.ca

For all other questions contact Dr. Manuel Riemer (contact information provided above) or Ms. Stephanie Whitney at stephanie.whitney@uwaterloo.ca or (519) 888-4567, ext. 31551.

PARTICIPATION

Your participation in this study is voluntary; you may decline to participate without penalty. If you decide to participate, you may withdraw from the study at any time without penalty and without loss of benefits to which you are otherwise entitled. If you withdraw from the study, your contributions in the focus group discussions will not be included in the analysis. However, if you withdraw from the study after the transcripts have been de-identified we will be unable to remove your data from the file. You have the right to omit any question(s)/procedure(s) you choose. Please note that there is no compensation being offered for participating in this study.

FEEDBACK AND PUBLICATION

The findings of this study are likely to be presented at scientific and professional conferences and published in scientific journals. The findings may be made available through Open Access resources. We will also develop a report of the findings from the overall study for BOMA Canada and BOMA Canada, and Sustainable Waterloo Region for public access no later than April 30th, 2018. You can also receive a copy of the study's findings via email. If you would like to be emailed a copy of the findings please provide your email address here: [text box to enter email address]. This information will be destroyed as soon as the feedback is sent to you (no later than April 30th, 2018).

CONSENT FOR QUOTATIONS

Sometimes researchers use quotations from participants to emphasize certain points in presentations and published papers. We would like to ask for your permission to use quotations from your data. Your name will not be linked to the quotations and we will remove any potentially identifying information before quotations will be used.

Please indicate how we may quote you in publications:

[ ] I give blanket consent for my de-identified quotes may to be used in any way (publications, presentations, etc.).

[ ] You can quote me, but I would like an opportunity to review how the quote is used before it is used.

Please contact me at: _____
You will be contacted before April 30th, 2018.

If you do not feel comfortable to share your de-identified quotations please select 'I do not want to participate' below.

CONSENT FOR PARTICIPATION

I have read and understand the above information. **I agree to participate** in this study. ___

I have read and understand the above information. **I do not want to participate** in this study.___

CONSENT FOR AUDIO RECORDING

I agree to be audio recorded for data analysis purposes . [Y/N]

Name (please print): _____

Signature: _____

We recommend that you print or save a copy of this form for your records. By giving your consent, you are not waiving your legal rights or releasing the investigator(s) or involved institution(s) from their legal and professional responsibilities.

Recruitment Email – From BOMA to Building Manager (note BOMA's CEO may make minor revisions)

Dear [NAME],

With this email I am introducing you to a research study that BOMA Canada is conducting, in collaboration with a research team from Wilfrid Laurier University, and the University of Waterloo. The research topic is sustainability in office buildings and, specifically, the performance gap in commercial office buildings. BOMA Canada is undertaking this research initiative in order to support our membership with thought leadership in this important and highly relevant topic. This research work will also support the development of practical resources that our members can use, in their organizations' journeys towards sustainability.

Your participation is completely voluntary. The link below will take you to an online survey, which includes two questions:

1. Do you give the research team permission to contact you, in order to provide more information about this project, and to invite you to participate further? If so, please provide your email address and phone number in the fields, below.
2. What is your preferred method of contact (email or phone)?

BOMA Canada and BOMA Toronto will not be informed whether or not you choose to participate. Your decision to participate or not participate in this study will have no effect on your relationship with BOMA Canada.

If you agree to be contacted by the research team, you will receive an email or phone call from the Principal Investigator, Dr. Manuel Riemer, an Associate Professor at Wilfrid Laurier University. Dr. Riemer will provide further details about the study.

If you have any questions about BOMA Canada's collaboration in this project, please do not hesitate to contact me. BOMA Canada strongly supports this research, and I personally feel that the results will be directly useful and beneficial to all of our membership organizations.

Thank you, in advance, for your consideration.

Best regards,

Benjamin Shinewald

President & CEO, BOMA Canada

Recruitment Email – From property management organization to Operations Staff (note contact may make minor revisions)

Dear [NAME],

With this email I am introducing you to a research study that the Building Operators and Managers Association (BOMA) of Canada is conducting, in collaboration with a research team from Wilfrid Laurier University, and the University of Waterloo. [NAME OF PROPERTY MANAGEMENT ORGANIZATION] is connected to this research through our membership in BOMA Canada. The research topic is sustainability in office buildings and, specifically, the performance gap in commercial office buildings.

The research team is seeking participants to interview in order to get the perspective of various stakeholders within commercial buildings including operations staff.Your participation is completely voluntary. The link below will take you to an online survey, which includes two questions:

1. Do you give the research team permission to contact you, in order to provide more information about this project, and to invite you to participate further? If so, please provide your email address and phone number in the fields, below.
2. What is your preferred method of contact (email or phone)?

[NAME OF PROPERTY MANAGEMENT ORGANIZATION] will not be informed whether or not you choose to participate.Your decision to participate or not participate in this study will have no effect on your relationship with [NAME OF PROPERTY MANAGEMENT ORGANIZATION.

If you agree to be contacted by the research team, you will receive an email or phone call from the Principal Investigator, Dr. Manuel Riemer, an Associate Professor at Wilfrid Laurier University. Dr. Riemer will provide further details about the study.

If you have any questions about BOMA Canada's collaboration in this project, please do not hesitate to contact me. BOMA Canada strongly supports this research, and I personally feel that the results will be directly useful and beneficial to all of our membership organizations.

Thank you, in advance, for your consideration.

Best regards,

[NAME OF CONTACT]

[NAME OF PROPERTY MANAGEMENT ORGANIZATION]_____

Recruitment Email – From property management organization to Tenant (note contact may make minor revisions)

Dear [NAME],

With this email I am introducing you to a research study that the Building Operators and Managers Association (BOMA) of Canada is conducting, in collaboration with a research team from Wilfrid Laurier University, and the University of Waterloo. [NAME OF PROPERTY MANAGEMENT ORGANIZATION] is connected to this research through our membership in BOMA Canada. The research topic is sustainability in office buildings and, specifically, the performance gap in commercial office buildings.

The research team is seeking participants to interview in order to get the perspective of various stakeholders within commercial buildings, including tenants. Your participation is completely voluntary. The link below will take you to an online survey, which includes two questions:

1. Do you give the research team permission to contact you, in order to provide more information about this project, and to invite you to participate further? If so, please provide your email address and phone number in the fields, below.
2. What is your preferred method of contact (email or phone)?

[NAME OF PROPERTY MANAGEMENT ORGANIZATION] will not be informed whether or not you choose to participate. Your decision to participate or not participate in this study will have no effect on your relationship with [NAME OF PROPERTY MANAGEMENT ORGANIZATION].

If you agree to be contacted by the research team, you will receive an email or phone call from the Principal Investigator, Dr. Manuel Riemer, an Associate Professor at Wilfrid Laurier University. Dr. Riemer will provide further details about the study.

If you have any questions about BOMA Canada's collaboration in this project, please do not hesitate to contact me. BOMA Canada strongly supports this research, and I personally feel that the results will be directly useful and beneficial to all of our membership organizations.

Thank you, in advance, for your consideration.

Best regards,

[NAME OF CONTACT]

[NAME OF PROPERTY MANAGEMENT ORGANIZATION]_____

Recruitment Email – From research team to Building Manager (this will be sent once BOMA members have given their permission to contact them)

Dear [NAME],

With this email I am inviting you to participate in a study being conducted on sustainability in office buildings and, specifically, the performance gap in commercial office buildings. We are interested to hear your insights regarding the motivations and barriers to engaging in sustainability practices within commercial office buildings. You completed a survey indicating your interest in receiving more information about this research project, which is being conducted in collaboration with BOMA Canada. We would like to invite you to participate in this project. Both BOMA Canada and BOMA Toronto are part of a leadership group working closely with our research team at Wilfrid Laurier University and the University of Waterloo. This study is part of the PhD thesis of Stephanie Whitney, who is supervised by Profs. Jennifer Lynes and Ian Rowlands, at the University of Waterloo. This study is part of a broader research project on the performance gap in commercial office buildings, being led by Prof. Manuel Riemer at Wilfrid Laurier University.

We are hoping to recruit approximately 10 building property managers (that may also own the managed property) with a gradation of assets under management, in Southwestern Ontario, to complete one interview (up to 60-minutes, but can be shorter) about their motivations and barriers to engaging in sustainability practices. During the interview, some discussions may involve considerations of demographic questions, such as age and gender, which may also be recorded.

Your participation is completely voluntary. BOMA Canada and BOMA Toronto will not be informed whether or not you choose to participate. Your decision to participate or not participate in this study will have no effect on your relationship with your industry association, BOMA Canada.

If you are interested in learning more about this study, or in participating, please see the attached information letter [informed consent form attached], and/or contact the research team at CSEwaterloo@gmail.com or me personally, Dr. Manuel Riemer, by phone at (519) 884-0710, extension 2982 or email at mriemer@wlu.ca.

Thank you for your consideration.

Manuel Riemer, Principal Investigator

Please note that this project, *Fostering sustainable behaviors in an iconic green office building,* has been reviewed and approved by the Wilfrid Laurier Research Ethics Board (REB #4896).

This study has also been reviewed and received ethics clearance through a University of Waterloo Research Ethics Committee (ORE#21928). If you have questions for the Committee contact the Chief Ethics Officer, Office of Research Ethics, at 1-519-888-4567 ext. 36005 or ore-ceo@uwaterloo.ca

Recruitment Email – From research team to Operations Staff (this will be sent once staff have given their permission to contact them)

Dear [NAME],
With this email I am inviting you to participate in a study being conducted on sustainability in office buildings and, specifically, the performance gap in commercial office buildings. We are interested to hear your insights regarding the motivations and barriers to engaging in sustainability practices within commercial office buildings. You completed a survey indicating your interest in receiving more information about this research project, which is being conducted in collaboration with BOMA Canada. We have interviewed a representative of [NAME OF PROPERTY MANAGEMENT ORGANIZATION] as part of this research, and we are looking to interview a member of the operations team that maintains buildings for [NAME OF PROPERTY MANAGEMENT ORGANIZATION]. We would like to invite you to participate in this project. [NAME OF PROPERTY MANAGEMENT ORGANIZATION] is connected to our research through their membership in the Building Operators and Managers Association (BOMA) of Canada. BOMA Canada and BOMA Toronto are part of a leadership group working closely with our research team at Wilfrid Laurier University and the University of Waterloo. This study is part of the PhD thesis of Stephanie Whitney, who is supervised by Profs. Jennifer Lynes and Ian Rowlands, at the University of Waterloo. This study is part of a broader research project on the performance gap in commercial office buildings, being led by Prof. Manuel Riemer at Wilfrid Laurier University.
We are hoping to recruit approximately 10 operations staff within commercial office buildings, in Southwestern Ontario, to complete one interview (approximately 10-15 minutes) about their motivations and barriers to engaging in sustainability practices. During the interview, some discussions may involve considerations of demographic questions, such as age and gender, which may also be recorded.
Your participation is completely voluntary. [NAME OF PROPERTY MANAGEMENT ORGANIZATION] will not be informed whether or not you choose to participate. Your decision to participate or not participate in this study will have no effect on your relationship with your contracted client, [NAME OF PROPERTY MANAGEMENT ORGANIZATION].
If you are interested in learning more about this study, or in participating, please see the attached information letter [informed consent form attached], and/or contact the research team at CSEwaterloo@gmail.com or me personally, Dr. Manuel Riemer, by phone at (519) 884-0710, extension 2982 or email at mriemer@wlu.ca.

Thank you for your consideration.

Manuel Riemer, Principal Investigator

Please note that this project, *Fostering sustainable behaviors in an iconic green office building*, has been reviewed and approved by the Wilfrid Laurier Research Ethics Board (REB #4896).

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Recruitment Email – From research team to Tenant

Dear [NAME],

With this email I am inviting you to participate in a study being conducted on sustainability in office buildings and, specifically, the performance gap in commercial office buildings. We are interested to hear your insights regarding the motivations and barriers to engaging in sustainability practices within commercial office buildings. You completed a survey indicating your interest in receiving more information about this research project, which is being conducted in collaboration with BOMA Canada. We have interviewed a representative of [NAME OF PROPERTY MANAGEMENT ORGANIZATION] as part of this research, and we are looking to interview a tenant of a building managed by [NAME OF PROPERTY MANAGEMENT ORGANIZATION].We would like to invite you to participate in this project. [NAME OF PROPERTY MANAGEMENT ORGANIZATION] is connected to our research through their membership in the Building Operators and Managers Association (BOMA) of Canada. Both BOMA Canada and BOMA Toronto are part of a leadership group working closely with our research team at Wilfrid Laurier University and the University of Waterloo. This study is part of the PhD thesis of Stephanie Whitney, who is supervised by Profs. Jennifer Lynes and Ian Rowlands, at the University of Waterloo. This study is part of a broader research project on the performance gap in commercial office buildings, being led by Prof. Manuel Riemer at Wilfrid Laurier University.

We are hoping to recruit approximately leadership representatives from 10 tenants within select property managers' asset portfolios, in Southwestern Ontario, to complete one interview (up to 60-minutes, but can be shorter) about their motivations and barriers to engaging in sustainability practices. During the interview, some discussions may involve considerations of demographic questions, such as age and gender, which may also be recorded.

Your participation is completely voluntary. [NAME OF PROPERTY MANAGEMENT ORGANIZATION] will not be informed whether or not you choose to participate. Your decision to participate or not participate in this study will have no effect on your relationship with your landlord, [NAME OF PROPERTY MANAGEMENT ORGANIZATION].

If you are interested in learning more about this study, or in participating, please see the attached information letter [informed consent form attached], and/or contact the research team at CSEwaterloo@gmail.com or me personally, Dr. Manuel Riemer, by phone at (519) 884-0710, extension 2982 or email at mriemer@wlu.ca.

Thank you for your consideration.

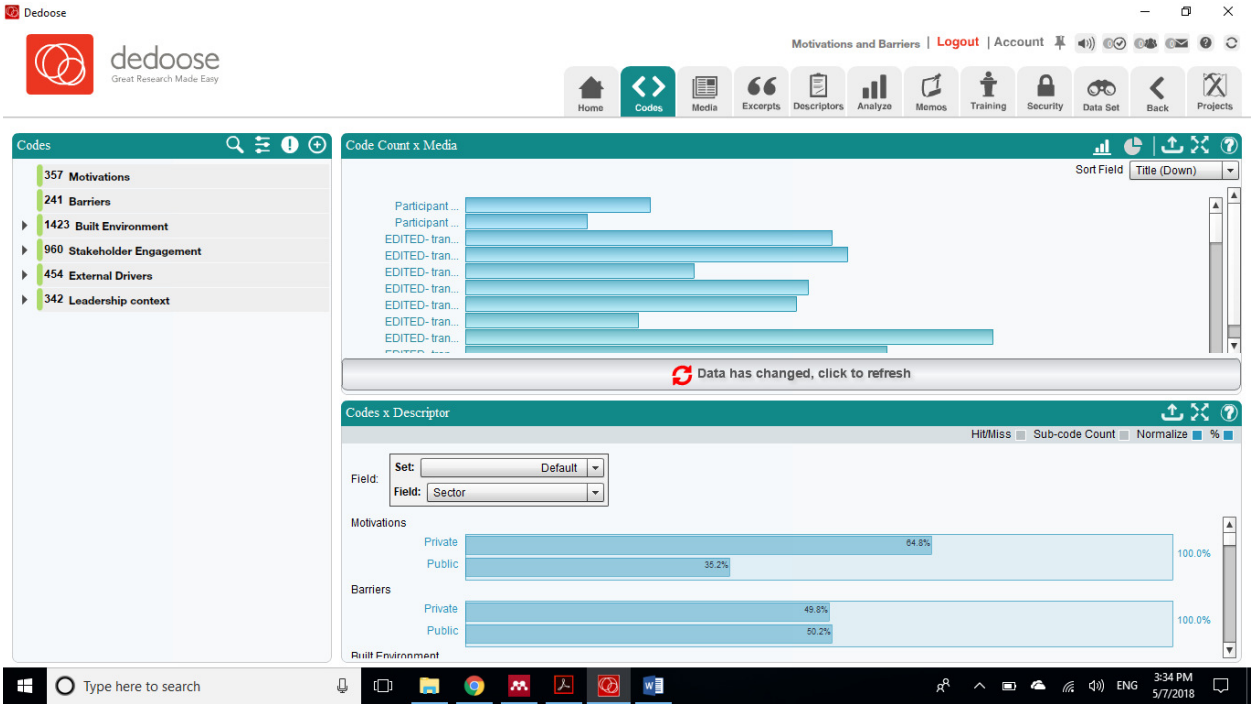
Manuel Riemer, Principal Investigator

Please note that this project, *Fostering sustainable behaviors in an iconic green office building,* has been reviewed and approved by the Wilfrid Laurier Research Ethics Board (REB #4896).

This study has also been reviewed and received ethics clearance through a University of Waterloo Research Ethics Committee (ORE#21928). If you have questions for the Committee contact the Chief Ethics Officer, Office of Research Ethics, at 1-519-888-4567 ext. 36005 or ore-ceo@uwaterloo.ca

Appendix I

Coding excerpt from Dedoose


Dedoose
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Great Research Made Easy
Motivations and Barriers | Logout | Account
Home
Codes
Media
Excerpts
Descriptors
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Memos
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Security
Data Set
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Projects
Codes
357 Motivations
241 Barriers
1423 Built Environment
960 Stakeholder Engagement
454 External Drivers
342 Leadership context
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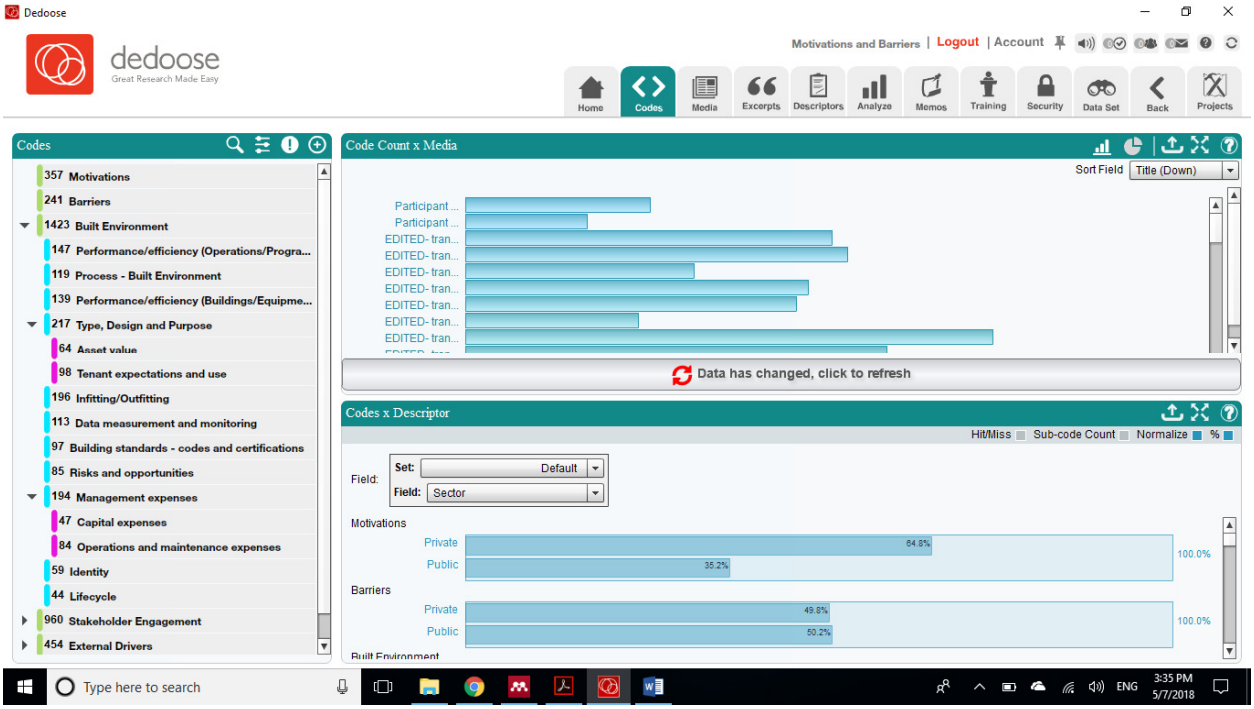
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Projects
Codes
357 Motivations
241 Barriers
1423 Built Environment
147 Performance/efficiency (Operations/Progra...
119 Process - Built Environment
139 Performance/efficiency (Buildings/Equipme...
217 Type, Design and Purpose
64 Asset value
98 Tenant expectations and use
196 Infitting/Outfitting
113 Data measurement and monitoring
97 Building standards - codes and certifications
85 Risks and opportunities
194 Management expenses
47 Capital expenses
84 Operations and maintenance expenses
59 Identity
44 Lifecycle
960 Stakeholder Engagement
454 External Drivers
Code Count x Media
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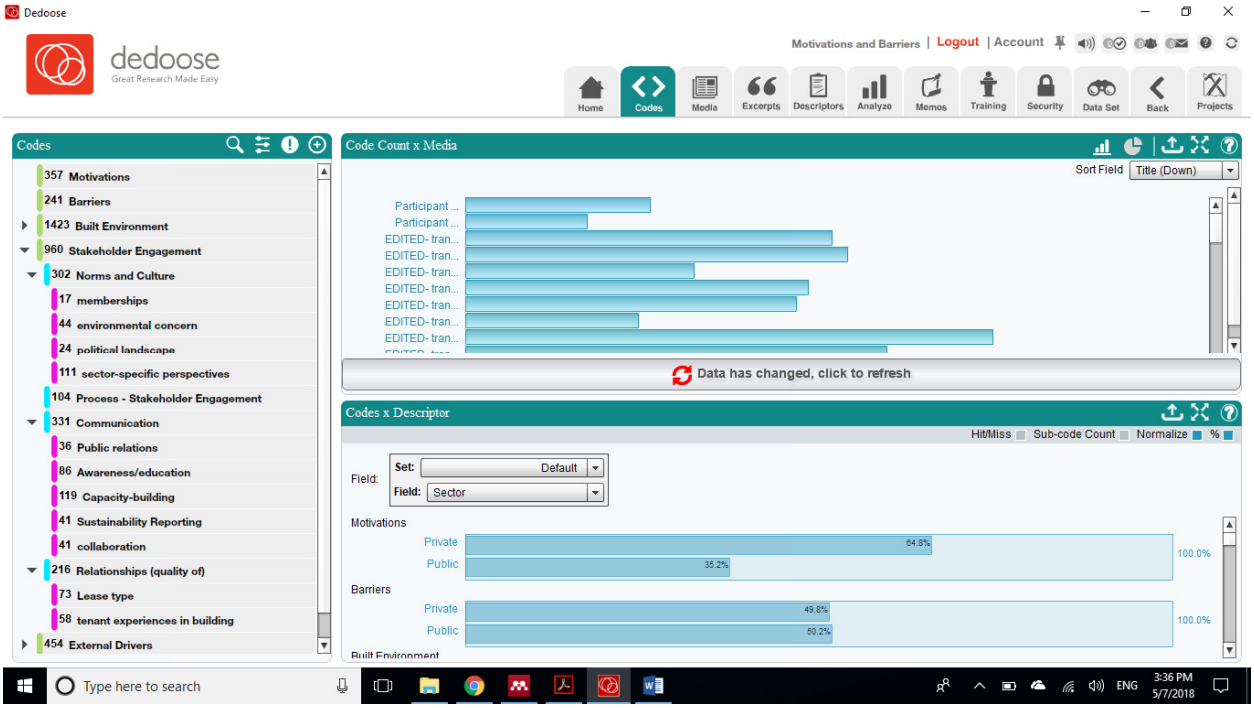
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Data Set
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Projects
Codes
357 Motivations
241 Barriers
1423 Built Environment
960 Stakeholder Engagement
302 Norms and Culture
17 memberships
44 environmental concern
24 political landscape
111 sector-specific perspectives
104 Process - Stakeholder Engagement
331 Communication
36 Public relations
86 Awareness/education
119 Capacity-building
41 Sustainability Reporting
41 collaboration
216 Relationships (quality of)
73 Lease type
58 tenant experiences in building
454 External Drivers
Code Count x Media
Sort Field
Title (Down)
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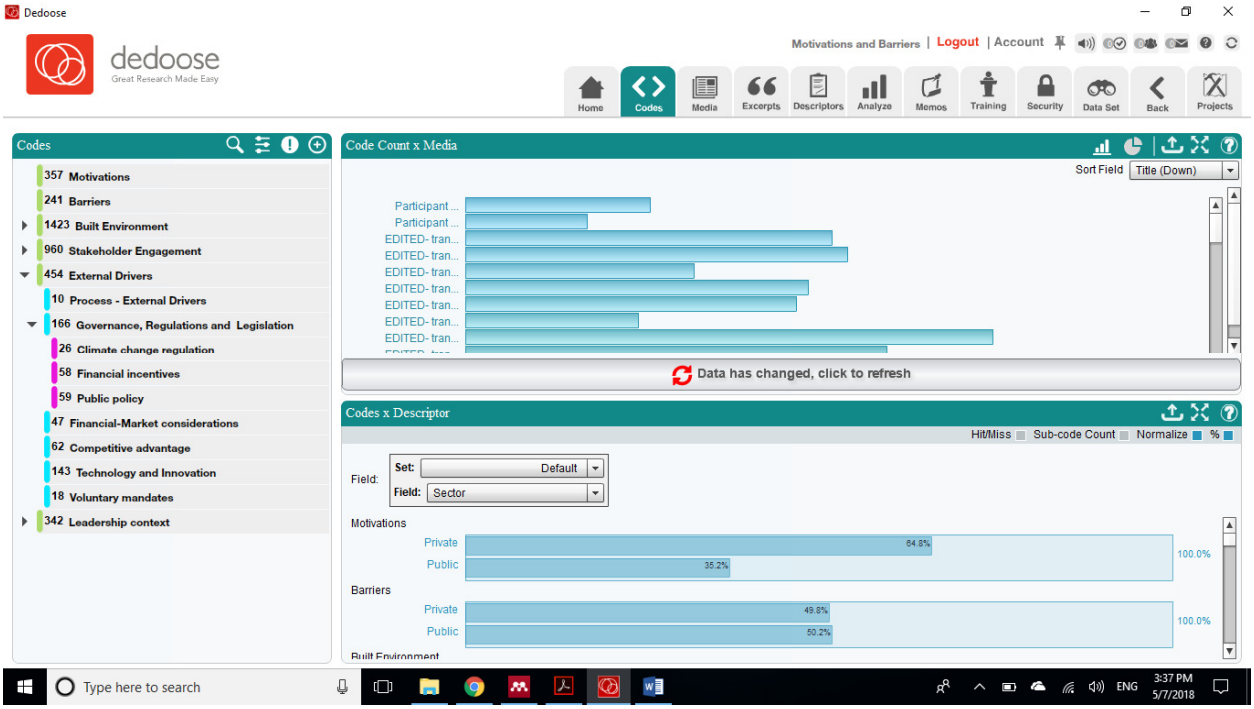
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Security
Data Set
Back
Projects
Codes
357 Motivations
241 Barriers
1423 Built Environment
960 Stakeholder Engagement
454 External Drivers
10 Process - External Drivers
166 Governance, Regulations and Legislation
26 Climate change regulation
58 Financial incentives
59 Public policy
47 Financial-Market considerations
62 Competitive advantage
143 Technology and Innovation
18 Voluntary mandates
342 Leadership context
Code Count x Media
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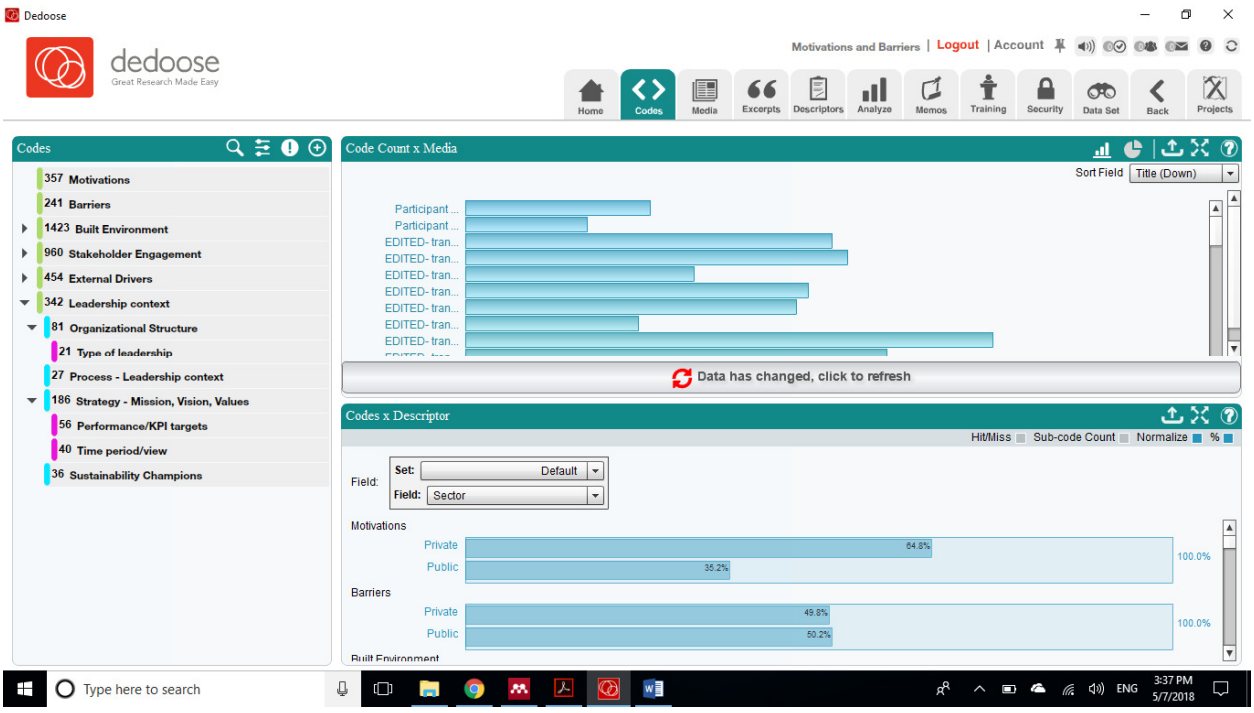
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Projects
Codes
357 Motivations
241 Barriers
1423 Built Environment
960 Stakeholder Engagement
454 External Drivers
342 Leadership context
81 Organizational Structure
21 Type of leadership
27 Process - Leadership context
186 Strategy - Mission, Vision, Values
56 Performance/KPI targets
40 Time period/view
36 Sustainability Champions
Code Count x Media
Sort Field
Title (Down)
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Appendix J

Qualitative Codebook

Theme	Theme Definition	Sub-Theme	Sub-Theme Definition	Sub-Theme Example Quotes		
Theme 1. Built Environment	The built environment is, simply put, the existing building stock. Axon et al (2012) further describe the building stock to include: age, condition, use, etc. According to the Centre for Education in the Built Environment (2011, cited in duToit & Mouton, 2013), 'built environment' refers to disciplines such as architecture, urban design, urban and regional planning (or just 'planning'), housing, construction, surveying and real estate.	Type, Design and purpose	The purpose of a building is to provide a clean, safe, and comfortable environment for work or leisure (citations?). Key guiding design principles to minimize the energy performance gap include: minimizing energy needs for building operation, matching the quality of energy with its use, using building automation systems to minimize total bulding use, enabling net effect through renewables and waste heat harvesting (Fedoruk et al, 2015). See cell J2 for definition RE. asset value	"That's what we want to be, whether it becomes a **value proposition** renting space in our building versus someone else's, what do we get? Well you've got a nice place to work. You get great people to work with and that run your building that have your best interests at hand. There's no other decision to be made other than to stay when it comes time to renewal or even a new deal." (P38) There are quite a few non-profit organizations that do programming out of our buildings. There are services that we provide for them….we pretty much look after the whole building. (P6)	"So as a stakeholder of the City, we would be advocating on that behalf, making sure we have the best architecture, the best urban design coming forward, the place making. All of that is what's essential in that city-building context…the way it (a building) interacts with the street is vital... actually it's essential to humans. And we want it for better Cities." (P34) "So the way the math has worked until recently was a focus on simple payback. So if I'm going to spend a thousand bucks on lighting. How long is it going to take me to recoup in terms of avoided energy cost a thousand bucks that I spend on that lighting upgrade? And often times over the past number of years there's been a focus on I want to get a payback one or two years. I've got to get at least 500 bucks back saved every year. That math, perhaps in part because commercial real estate and real estate in Canada, except for the challenges we face in Alberta, there's a tailwind behind prices and they're going up and it's a chase for yield. And now there's a recognition that in terms of its value you can use a evaluation framework to figure out where you're going to park your money." (P15)	"The philsophy change around (the) purpose of built buildings: So we're shifting away from, there's still a certain specialty (that) has to occur when you're building something for a specific **program**. However, there's also other things that you can kind of generalize a little bit more, and it's not saying that everything sits on casters and everything is totally mobile... but now as a City, we're trying to be a lot more integrated where it doesn't matter. It (the building) could become anyone's in the near future and it needs to do dual/triple purposes that way." (P34)

Aspects of Sub-Theme	Aspects of Sub-Theme Definition	Aspects Example Quotes		
ASSET VALUE Defining characteristics (don't necessarily want a sub-code, but want to capture differentiations such as old vs. new buildings, office vs. retail, heritage buildings, etc.) may also need a place for building location and access to transit	"For example, Energy Performance Certificates (EPCs) and Display Energy Certificates (DECs) (in the UK) assess environmental performance, and these metrics should be reflected in the pricing of property assets, and hence values, in the market. However, if there is no market differentiation in terms of either occupier or investor demand, between a building that displays strong sustainability credentials and one that does not, there will be no impact on value....within the UK, the US and other mature and transparent markets, there are signs that, increasingly, sustainability criteria matter to property owners (be they owner occupiers or investors) and to tenants. Where this can be demonstrated as affecting pricing through analysis of comparable transactions, the **valuation** should be adjusted accordingly (RICS, 2009)." (Axon et al, 2012)	"The retail tenants for the most part, like in a strip centre would have their own utilities. Because it's easier to separately meter every bay, right? In a building like this one (office tower), we have a global meter and then we pay our utility bill…whatever it is per month or per year, and it's divided amongst the square footage. (P38) "There's all kinds of **emerging trends in office space**… Proximity to the airport sometimes matters… with US companies… they'd rather be in the West end.. As opposed to going downtown… what we're seeing, a greater trend, is locating around suburban transit. So for example Vaughan right now, I think by the end of the year, they're going to have the TTC going all the way up to Highway 7. Well a few tenants are now targeting that market, and they're usually larger tenants... the rationale is that they can	(The typical length of a rental agreenment is) 10 years-10 to 15. Yeah it's a long term lease. And here's the other thing why that piece of information is critical,(is) because the **actual value of the building**, for the most part, is determined by the net present value of your long term leases...you can have a building that's the latest and the greatest, but no tenants. It is worth nothing, right? So it's not what the building from a construction standpoint or the energy efficiency features within the building, but it's also how well that building is actually serving their ultimate purpose of making money." (P9)	
Tenant Expectations	"conceptual model that perceived service quality can be determined through a function of two measures: **customer expectations** of a service; and customer perceived service performance" (Parasuraman et al., 1985, cited in Parkinson et al, 2013, p1495). I use this term to refer to tenants' expectations of their building (i.e. related to the infrastructure - their expectations with respect to the property manager's programs would be captured under Relationships)	"Sometimes you'll get tenants (to) whom we have no obligation to have a building that is certified in any way, but they want to know..what are our recycling policies, what are we doing, what are our garbage removal and waste reduction policies? What are we doing for energy reduction? They want to know a lot of those things. they hear that we have electric vehicle chargers that are supposed to be coming in, to be installed. They want to know the details...I even asked them, 'do you have associates that drive electric vehicles', and they say no. It's a part of their	"You started hearing about it 10 years ago. It started with BOMA Best…then you started hearing about LEED. So everyone is aiming for LEED…for BOMA Best Gold…it's in the forefront. It's what everybody's doing. It's morphed itself from 10 years ago, some visionaries were doing it, because they wanted to. Now you're doing it, it's an expectation or you waon't get a tenant. You won't get certain tenants to move into your building unless you offer....the same amenities, the same green....it's an expecation that everyone wants to be in a green building, everyone wants a LEED	"These are LED strip fixtures..we've taken the tubes out and put in the LED refurbishment. This is a new technology, so we have about a quarter of the lights on this floor that you normally have. On another floor, for every one (of these), you'd have three more. And how we manage people with light sensitivities is we just turn off the fixture. But, because there's less light (fixtures) on this floor, and not to create a cave thing, it's also very difficult to turn them off. They're light Christmas lights. we actually don't let people turn off the lights. So now you have people who are used to dark work settings and they're now complaining about the lights." (P32) This shows limitations to new technology that is very efficient in addressing occupant needs

Appendix K

Cumulative Code Count from Dedoose

FINAL CODES AND CUMULATIVE COUNT

Themes have been sorted in order of highest code count (Level 1 codes are cumulative)

Count	Level	Code
357	1	Motivations
241	1	Barriers
1423	1	Built Environment
217	2	Type, Design and Purpose
64	3	Asset Value
98	3	Tenant expectations and use
196	2	Infitting/Outfitting
194	2	Management Expenses
47	3	Capital Expenses
84	3	Operations/maintenance expenses
139	2	Performance and Efficiency (Building/Equipment)
147	2	Performance and Efficiency (Operational/Programs)
113	2	Data measurement and monitoring
119	2	Process - Built Environment
97	2	Building standards - code and certifications
85	2	Risks and Opportunities
59	2	Identity
44	2	Lifecycle
960	1	Stakeholder Engagement
331	2	Communication
36	3	Public relations
119	3	Capacity-building (training)
86	3	Awareness/Education (programming)
41	3	Sustainability Reporting
41	3	Collaboration
286	2	Norms and Culture
17	3	Memberships
44	3	Environmental concern
24	3	Political landscape
111	3	Sector-specific perspectives
216	2	Relationships (quality of)
73	3	Lease type
58	3	Tenant experiences in the building
104	2	Process - Stakeholder Engagement
454	1	External Drivers
166	2	Governance/Regulation/Legislation
26	3	Climate change regulation
59	3	Public policy
58	3	Financial incentives

143	2		Technology and Innovation	
62	2		Competitive Advantage	
47	2		Financial - Market Considerations (prices, etc.)	
18	2		Voluntary Mandates	
10	2		Process - External Drivers	
342	1	Leadership Context		
36	2		Sustainability Champions	
186	2		Strategy - Mission, Vision, Values	
56	3			Performance targets/KPI
40	3			Time period/view
81	2		Organizational structure	
21	3			Type of leadership
24	2		Process - Leadership Context	

Appendix L

Cumulative Code Count, Co-Occurrences, and Presence

	Motivation	Barriers	Built Envir	Performan	Proces	Perfor	Type,	Asset	Tenan	Infittin	Data r	Buildir	Risks	Manag	Capita	Opera	Identit	Lifecy	Stakel	Norms
Motivations		5	1	19	8	15	3	23	31	8	21	21	18	16	5	26	17	8		12
Barriers	5			14	8	9	9		15	7	14	10	9	15	17	12	14	5		23
Built Environment	1				1		1		1	2			2						1	2
Performance/efficiency (Operations/Pro	19	14			5	4	3	3	4	17	22	5	3	1	1	13	3	2		5
Process - Built Environment	8	8	1	5		3	2		5	8	4	5	7	5	2	2	1	3		7
Performance/efficiency (Buildings/Equip	15	9		4	3		7	2	2	10	12	10	5	5	11	9	1	13	1	5
Type, Design and Purpose	3	9	1	3	2	7				5	1	3	8	1				1		5
Asset value	23			3		2			2	4	2	4	4	4		5	4			1
Tenant expectations and use	31	15	1	4	5	2		2		2	2	8	1	2	2	5	4	3		3
Infitting/Outfitting	8	7	2	17	8	10	5	4	2		14	6	6	3	1	1	2	2	1	2
Data measurement and monitoring	21	14		22	4	12	1	2	2	14		2			2	5	1		1	
Building standards - codes and certifica	21	10		5	5	10	3	4	8	6	2		4	2	2	6	3	3		6
Risks and opportunities	18	9	2	3	7	5	8	4	1	6		4		3		5		5		2
Management expenses	16	15		1	5	5	1	4	2	3		2	3		1		3	3		
Capital expenses	5	17		1	2	11			2	1	2	2		1		2		5		1
Operations and maintenance expenses	26	12		13	2	9		5	5	1	5	6	5		2		2	1		1
Identity	17	14		3	1	1		4	4	2	1	3		3		2		2		1
Lifecycle	8	5		2	3	13	1		3	2		3	5	3	5	1	2			1
Stakeholder Engagement			1			1				1	1									1
Norms and Culture	12	23	2	5	7	5	5	1	3	2		6	2		1	1	1	1	1	
memberships	6					1				1	1	2	1							
environmental concern	13	5	1	3	3	1		2	3	3		1	1	1		1	1			
political landscape	6	8				1	3		1	1			1	2						
sector-specific perspectives	20	17		3	3	4	5	5	5	3	6	4	7	3	2	2	4			3
Process - Stakeholder Engagement	8	15		3	10	1		3	5	6	5	3	1	1			3			5
Communication	2	3			1					1										1
Public relations	9	5			1	1			3	1	2	3		2		1				1
Awareness/education	15	10		5	3	1		1	5	10	6	1	3	1		2				9
Capacity-building	16	17		23	3	7	2	2		19	6	4	4	2		4	1	1		7
Sustainability Reporting	7	3		1	1	1			1	6	7	4	1						1	
collaboration	9	3		3	1	2		1			8		1							
Relationships (quality of)	25	18		3	2	3	2	1	7	11	3	1	2	2			2			2
Lease type	8	8		3	7	3	2	3	7	9	3	5	4	1	5	10	2			2

Appendix M

Statement of Contributions Signature Pages

Co-authorship (Chapter Two) for Jeffrey Demaine (Bibliometrics and Research Impact Librarian) was determined based on meeting the following criteria:

- Substantial contributions to the design and implementation of the bibliometric coupling analysis, and to interpretation of data;
- Review of the versions of the chapter that will be published as a refereed journal article;
- Contributions to editing and revising the work critically for important intellectual content, based on the peer-review process;
- Agreement to be accountable for all aspects of the contributed work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved.

I testify that Stephanie Whitney is the primary author of the manuscripts in this dissertation, that the work was dominated by her intellectual efforts, and that I have met the four tests outlined above.

Jeff Demaine Sept. 22nd 2018

Jeffrey Demaine (Bibliometrics and Research Impact Librarian)

University of Waterloo

Co-authorship (Chapters Three and Four) for Bianca Dreyer (PhD student) was determined based on meeting the following criteria:

- Substantial contributions to the development of the hierarchical linear model, and to interpretation of data (Chapter Three)
- Substantial contributions to the conceptual framework and qualitative codebook through validation of open and axial coding; conducted three of forty-three interviews;
- Review of the versions of the chapters that will be published as a refereed journal article;
- Contributions to editing and revising the work critically for important intellectual content, based on the peer-review process;
- Agreement to be accountable for all aspects of the contributed work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved.

I testify that Stephanie Whitney is the primary author of the manuscripts in this dissertation, that the work was dominated by her intellectual efforts, and that I have met the five tests outlined above.

_____

Bianca Dreyer (PhD student)

Wilfrid Laurier University

Co-authorship (Chapter Two) for Alexander Sasha Graham (PhD Student) was determined based on meeting the following criteria:

- Substantial contributions to the design and implementation of the co-citation analysis, and to interpretation of data;
- Review of the versions of the chapter that will be published as a refereed journal article;
- Contributions to editing and revising the work critically for important intellectual content, based on the peer-review process;
- Agreement to be accountable for all aspects of the contributed work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved.

I testify that Stephanie Whitney is the primary author of the manuscripts in this dissertation, that the work was dominated by her intellectual efforts, and that I have met the four tests outlined above.

Alexander Sasha Graham (PhD Student)

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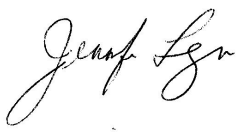
Co-authorship (Chapter Two) for Jennifer Lynes (Committee Member) was determined based on meeting the following criteria:

- Substantial contributions to the conception and design of the work, and to interpretation of data;
- Contributions to editing and revising the work critically for important intellectual content;
- Final approval of the versions of the chapter that will be published as a refereed journal article;
- Agreement to be accountable for all aspects of the contributed work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved.

I testify that Stephanie Whitney is the primary author of the manuscripts in this dissertation, that the work was dominated by her intellectual efforts, and that I have met the four tests outlined above.



_____

Jennifer Lynes (Committee Member)

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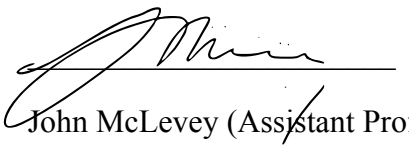
Co-authorship (Chapter Two) for John McLevey (Assistant Professor) was determined based on meeting the following criteria:

- Substantial contributions to the conception and design of the work, and to interpretation of data;
- Review of the versions of the chapter that will be published as a refereed journal article;
- Contributions to editing and revising the work critically for important intellectual content, based on the peer-review process;
- Agreement to be accountable for all aspects of the contributed work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved.

I testify that Stephanie Whitney is the primary author of the manuscripts in this dissertation, that the work was dominated by her intellectual efforts, and that I have met the four tests outlined above.



John McLevey (Assistant Professor)

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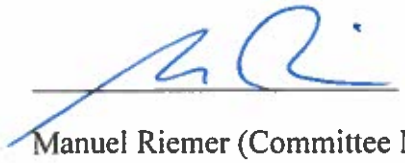
Co-authorship (Chapters Three and Four) for Manuel Riemer (Committee Member) was determined based on meeting the following criteria:

- Substantial contributions to the conception and design of the work, and to interpretation of data;
- Contributions to editing and revising the work critically for important intellectual content;
- Final approval of the versions of the chapters that will be published as refereed journal articles;
- Agreement to be accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved.

I testify that Stephanie Whitney is the primary author of the manuscripts in this dissertation, that the work was dominated by her intellectual efforts, and that I have met the four tests outlined above.



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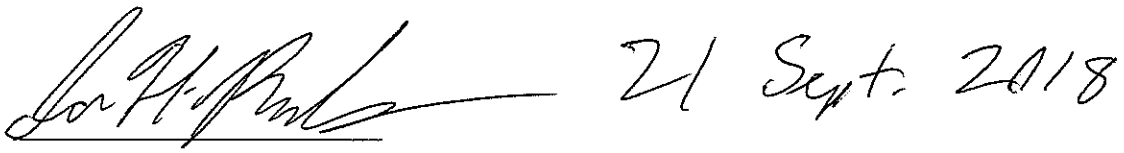
Co-authorship (Chapter Three) for Ian Rowlands (Advisor) was determined based on meeting the following criteria:

- Substantial contributions to the conception and design of the work, and to interpretation of data;
- Contributions to editing and revising the work critically for important intellectual content;
- Final approval of the versions of the chapter that will be published as a refereed journal article;
- Agreement to be accountable for all aspects of the contributed work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved.

I testify that Stephanie Whitney is the primary author of the manuscripts in this dissertation, that the work was dominated by her intellectual efforts, and that I have met the four tests outlined above.



21 Sept. 2018

Ian Rowlands (Advisor)

University of Waterloo