Physical versus behavioural emissions reductions: Quantifying and comparing emissions reduced by behaviour and emissions reduced by technology of net-zero communities

by

PersonGuy Hu

A thesis

presented to the University of Waterloo

in fulfillment of the

thesis requirement for the degree of

Master of Environmental Studies

in

Planning

Waterloo, Ontario, Canada, 2023

Author's Declaration

I hereby declare that I am the sole author of this thesis. This is a true copy of the thesis, including any required final revisions, as accepted by my examiners.

I understand that my thesis may be made electronically available to the public.

Abstract

Modern climate change research calls for more diverse and creative solutions past simply improving technology; there is not one solution to climate change. A multidisciplinary field like planning can affect both physical changes in a city or behaviour changes in people to reduce greenhouse gas emissions. Despite these considerations, behavioural emissions reductions remain an underexplored topic of literature, especially in terms of emission quantification. Without this information, planners cannot make the most informed and resource efficient policy decisions to combat climate change. This thesis fills this literature gap by quantifying behavioural emissions reductions and comparing them to the best-case scenario for physical emissions, net-zero communities, in the context of Ontario's first, recently completed, net-zero community located in London, Ontario. This thesis also begins to explore relationships and patterns between sources of behavioural emissions reductions and how they can compound into greater reductions. Within the study area, net-zero homes produced 6.89 fewer tonnes of CO_2e/year compared to the average home, 67.5% of which were physical emissions reductions and 32.5% of were behavioural. Residents here generally improved few behaviours to a large magnitude rather than improving many/all behaviours to a small magnitude. While no specific behaviour patterns were identified, the there was evidence in favour of patterns existing, which could by identified with a larger sample. Overall, while behavioural emissions reductions were less effective than physical, they can be implemented both concurrently and instead of physical when necessary. There is also potential for behavioural emissions reductions to be more effective than physical given the right context and if behavioural patterns are used to their fullest.

Acknowledgements

No thesis is achieved alone, least of all this one. Without the aid and support of a whole host of people both me and my thesis would be completely lost. First, I would like to give my utmost thanks to my advisor Jeremy Pittman who both guided me every step of the way and gave me confidence when it was lacking. Thank you to my committee members Jeffrey Wilson, Markus Moos and Mark Seasons for your feedback and support throughout the process. A thank you to the School of Planning, the Department of Geography and Env Management and the entire Faculty of Environment for accepting me for all am and being my home for the past 8 years. Thanks to those who physically helped my survey including the good people at Central Stores for mailing my survey, my friend Yash for taking me to London for door-to-door surveys and all those who responded to my survey. And a special thanks to my Planning cohort, a group of intelligent, gifted and fun people: I only wish COVID had not stopped us from meeting sooner.

I would also like to thank those in my personal life. Thanks to family, specifically to my parents, David and Sophia, my siblings, Ashley and Zachary, and their partners. Thank you to my friends from Mississauga, Waterloo and beyond who provided encouragement and support along the way. Thank you to the staff, guests and other volunteers at Ray of Hope community center who helped keep me sane and was my primary reason for leaving the house during COVID. Finally, a thank you to my personal lord and saviour Jesus Christ for saving my life physically, emotionally and spiritually.

Table of Contents

List of Figures

List of Tables

Chapter 1 – Exploring Alternative Climate Change Solutions

1.1 Introduction

Climate change is one of the biggest issues the global community faces; it is undeniable, it is urgent and it affects every single person (Agrawal & Lemos, 2015; Lemos & Agrawal, 2006). In today's climate landscape, there is a need for more varied and diverse emission reduction methods as better technology is not capable of meeting global emission targets (Agrawal & Lemos, 2015;Boies et al., 2009; Chapman, 2007; Elizondo et al., 2017; Johansson, 2009; Kromer er al., 2010; Lee & Lee, 2014; Morrow et al., 2010; Streimikiene & Volochovic, 2011; Zhivov et al., 2014; Wynes et al., 2018). Behaviour represents a sector of emission reduction solutions with the potential to meet the global emission targets and prevent further damage to the environment (Chapman, 2007; Johansson, 2009; Wynes et al., 2018). The question becomes just how much potential these solutions have, objectively speaking. Current literature does not do a sufficient job of providing a quantitative lens on behaviour, whether due to lack of scope, lack of quantification or lack of cohesive definitions (Chapman, 2007; Dietz et al., 2009; Streimikiene & Volochovic, 2011). Therefore, the primary goal of any study related to emission reducing behaviours should be to numerically quantify said behaviours.

Planning represents a field with the ability to deliver these behavioural solutions to a wide audience at both large and small scales and as such is able to make the most of this potential (Dietz et al., 2009; Shandiz et al., 2021). Planning already applies both technological solutions, therefore by adding behavioural solutions, planners will have a diverse set of tools with which the discipline can combat climate change in whatever way is best suited for whatever the geographic context dictates (Hammett et al., 2018; Higgins et al., 2011). To ensure that behavioural climate solutions are at their most effective for planners, these solutions must be able to be applied efficiently. Technological solutions have a very efficient solution in net-zero infrastructure, which combine multiple technological solutions, namely improved building envelopes and renewable energy, to effectively reduce emissions to zero (Bakhtavar et al., 2020). However, net-zero does not scale up well due to high cost and limits on renewable energy, meaning planners cannot implement it at any scale despite practicing at both large and small scales (Shandiz et al., 2021; Young & Brans, 2017). Optimally, behavioural solutions emulate this and will be able to combine multiple behaviours in a single solution to be able to address climate change not just on a variety of scales, but also at a high efficiency.

While net-zero is a good example for what behavioural emissions reductions should aim to achieve, it is difficult to compare net-zero to other methods of emission reduction. If comparing emissions from one solution to net-zero infrastructure, the other solution will be objectively inferior to an infinite degree from a numerical perspective. Net-zero research is not concerned with this issue, and instead focuses on improving scalability and reducing cost (Shandiz et al., 2021; Young & Brans, 2017). Therefore, to properly study and compare net-zero infrastructure to other emissions solutions, creative methods of quantifying and comparing emissions are necessary, methods which circumvent this issue of net-zero that have not been used in other literature however are based in literature.

The goal of this study is to investigate the intersection of climate change, planning and behaviour to fill the literature and applicative gap in current planning and climate change research. As such two research questions are outlined. First is "How do choices in behaviour alter the emissions a household produces?". Related to this are the two research objectives of quantifying emission changes as a result of choices and determining how behaviour-related emissions compare to technology-related emissions. Second is the research question "How effective are net-zero communities in reducing GHG emissions?" and the related research objective of determining if net-zero communities are worth increased investment. The ultimate goal is that these two questions come together to provide a planning solution that can be applied in conjunction with technological solutions to more effectively address climate change emissions.

1.2 Literature Review

1.2.1 Behaviour and Climate Change Emissions

One theme in recent climate change literature is that there is a need for more varied emission reducing methods rather than just technological improvements (Johansson, 2009; Kromer er al., 2010; Lee & Lee, 2014; Morrow et al., 2010; Streimikiene & Volochovic, 2011; Wynes et al., 2018). A balanced and holistic approach is needed or else progress in one sector could be negated by the lack of progress in other sectors (Boies et al., 2009; Chapman, 2007). Behaviour represents the sector which requires the most improvement (Chapman, 2007; Johansson, 2009; Wynes et al., 2018). While research into behaviour and climate change emissions has increased over the past ten years, there is still many aspects of this relationship that remain unknown, especially when considering the quantifiable benefits for each behavioural intervention (Chapman, 2007; Lee & Lee, 2014). Older studies which do acknowledge behaviour do not separate them from technological improvements (Joosen & Blok, 2001). Throughout this review and study, these behaviour-related emissions reducing methods will be referred to as emission reductions by behavioural interventions, or behavioural emissions reductions [BERs] for brevity. Meanwhile, emission reducing methods related to making technological improvements or physical changes to infrastructure or buildings will be referred to as physical emissions reductions [PERs].

One behaviour which planners have a great influence on that can lower carbon emissions is travel by altering the urban landscape (Lee & Lee, 2014). By reducing the need for travel either by planning amenities near residential zones or increasing population density through high density residential zones, people will travel less resulting in fewer vehicular emissions (Lee & Lee, 2014). While urban form has a greater impact on behaviour-related carbon emissions, it also reduces emissions via physical/infrastructural methods as higher density urban forms use less energy due to smaller homes and less energy loss on transfer (Lee & Lee, 2014). Altogether, a doubled population density can reduce emissions from travel by 48% and electricity usage by 35% in a North American context (Lee & Lee, 2014). This is a large reduction however not one that can be applied realistically to any context, especially a context which already has a high population density however it may be possible to emulate these results by focusing on altering the behaviours which these methods affect rather than just doubling population density (Lee & Lee, 2014). In some cases, it is also possible to emulate these with advanced technological improvements when they exist, such as using community-based electricity sharing when producing clean energy (Vindel et al., 2019).

This example reduces the loss on energy transfer because of less distance travelled as sources are now more localised but is specific to specific methods of energy generation like solar (Vindel et al., 2019). Examples of planning methods to emulate these changes are smart growth policies and the fifteen-minute city concept (Lee & Lee, 2014; Logan et al., 2022).

There are additional avenues in which better behaviour can lead to reduced emissions in the home. Research shows that the next most prominent source of emissions are household specific emissions: electricity and heating (Streimikiene & Volochovic, 2011). These emissions are affected both by improved technologies but also by individual behavioural choices (Streimikiene & Volochovic, 2011). In the technology vein, appliances which are more energy efficient can lower electricity usage and additionally help measure and manage clean energy generation (Fujimoto et al., 2017). Additionally, better insulated homes can reduce the need for heating and cooling further saving energy usage (Ayylidiz & Erdogan, 2022). In the behavioural vein, many small behaviour choices can compound into a large total effect, including behaviours related to: electrical amenity usage, cooking, light usage, showering and waste management (Streimikiene & Volochovic, 2011). In a lower population and population density country such as Lithuania, these behavioural reductions were able to equal the emissions reductions by switching from traditional power plant to nuclear power plants at a much cheaper price (Streimikiene & Volochovic, 2011).

Despite the reviewed improvements on behaviour resulting in reduced emissions, behaviour is complicated and is affected by many factors, not just environmental benefits (Chapman, 2007; Porras, 2020). For example, the best practice for home dish care from an environmental perspective is manual dishwashing rather than using a dishwasher, however there are other benefits to machine washing, such as saving time, which cause homeowners to prefer machines (Porras, 2020). Similarly, the most environmentally friendly methods of transportation do not always have the range, speed or convenience of personal, motor-vehicles (Chapman, 2007). Additionally, behaviour is also habitual which can work both for and against environmental impact (Shahmohammadi et al., 2019; Porras et al., 2020). These habits often need to be overcome as many habits, like shower length or food waste, increase and compound with other factors to increase environmental impact (Shahmohammadi et al., 2019; Porras et al., 2020).

To make environmentally improving behaviours the ones that are chosen, other encouragement is needed to improve their benefit or, when environmental benefits are the primary factor in decision making, information about these benefits must be more available (Meiklejohn et al., 2018; Meiklejohn et al., 2021; Reames, 2016). Therefore, as noted in many pieces of planning literature, when it comes to applying behavioural studies and converting it into policy or programs, there is an immense need for local context to shape the method for success (Jones & Kammen, 2011; Meiklejohn et al., 2018; Meiklejohn et al., 2021). This is a two-way process, where decision makers must inform the target audience but must also take insight and feedback from said audience (Meiklejohn et al., 2021). This is a recurring theme in the field of planning, that local context is an important consideration, and as such will be an important consideration throughout the study.

Overall, the literature has two themes when it comes to behavioural emissions reductions. First, is despite less research, there is evidence that behavioural emissions reductions have the potential to significantly affect emissions profiles (Dietz et al., 2009; Wynes et al., 2018). Second, is that the difference between behavioural emissions reductions and physical emissions reductions is murky. This is not directly stated in any of the literature however some emissions defined as behavioural in these studies, such as improved insulation, would be defined as physical based on the brief definitions provided in this review (Dietz et al., 2009). Meanwhile, in other studies, while most emission sources reviewed thus far would fall under the same category, the definitions are different, such as defining behavioural emissions reductions as any reduction that can be achieved free of cost (Streimikiene & Volochovic, 2011). Therefore, depending on how physical and behaviour are defined emission reductions may fall under both categories and therefore the delineation of the two is dependent on the researcher. For this study, because of the planning context, the key to defining behavioural reductions is who planning is done for and how planning is done. Planning is done for a wide audience through policy and alteration of the physical environment, therefore when defining behavioural emissions reductions this must be kept at the forefront; the definition should encompass a wide audience and consider the methods of planning (Dietz et al., 2009; Shandiz et al., 2021). Based on this, the basic definition of emission reductions by behavioural interventions is a change in the actions or habits of an individual which cause an increase/decrease in emissions opposed to emission reductions as a result of a physical change such as technology or built environment. The further specifics of defining behavioural emission reductions which are more specific to this study will be explored in later sections.

1.2.2 Measuring emissions

A major way to measure environmental impact is by quantifying greenhouse gas emissions, which has validity as the target metric outlined in the Kyoto protocol and other United Nations climate conferences and directly related to most climate projections related to the increase in average global temperatures (Streimikiene & Volochovic, 2011; Wynes et al., 2018). As noted, while research on the links between behaviour and emissions have increased dramatically over the past couple of decades, when considering them in quantitative lens, relevant research decreases.

While many aspects of emissions directly produce greenhouse gas emissions and can be measured, such as usage of gas-powered vehicles, many emission producing methods have an output which are not in greenhouse gases, such as electricity generation (Environment Climate Change Canada [ECCC], 2021).Techniques for emission categories which require quantification rather than direct measurement can differ slightly per source and within the same source but are all generally based on the premise of using conversion factors, from past research of self-derived, to convert an output from the base unit, such as kWh, to a weight of CO2e emitted per unit of time (Chen et al., 2019). These conversion factors are referred to as emissions factors or coefficients in emission quantification research and practice (Chen et al., 2019; Streimikiene & Volochovic, 2011; ECCC, 2021). This is ultimately the most relevant and universal method of quantification, which is applicable to almost any context (Wynes et al., 2018).

Quantification of greenhouse gas emissions in the past has focussed on technological improvements where behaviour is not acknowledged and attributed to technological improvement or behaviour is acknowledged but not separated from technological improvement (Joosen & Blok, 2001; Streimikiene & Volochovic, 2011). When technological methods are quantified, this is done by measuring technological outputs and applying emission factors to these outputs (Streimikiene & Volochovic, 2011). Because outputs are measured, the inputted reasoning cannot be separated, explaining why behaviour is not quantified or acknowledged in some cases (Chapman, 2007; Streimikiene & Volochovic, 2011).

Other studies which have done qualitative analyses of household emissions focus generally use modelled or estimated quantification methods rather than practical quantification methods (Boies et al., 2009; Duarte et al., 2014; Higgins et al., 2011). These methods often utilize models that assume a high level or random such as stochastic and diffusion models (Duarte et al., 2014; Higgins et al., 2011). These random models are effective when operating without much practical data or when generalizing over large scales but when considering planning and planning application may not be accurate or usable at every scale (Duarte et al., 2014). This is due to the importance of local context in most planning settings (Karunathilake et al., 2019; Lau, 2022; Schifman et al., 2017; Zhivov et al., 2014). This means there is a methodological gap in behavioural quantification research and an opportunity for quantification based on observed or measured results. The advantage of practical quantification is it accounts for local context better than a model which is important for decisions made at smaller scales, such as the community or municipal scale (Lindon, 2014). There are weaknesses to practical methods though: they take more time than other methods and have more margin for error (Lindon, 2014).

One practical method that professional fields use to quantify emissions is carbon accounting: a method of quantification which focuses on separating emissions into different usage scopes to understand the individual and general emissions sources (Chen et al., 2019; Tukker et al., 2020; Wang & Chen, 2018). In the context of planning and on a residential scale, the purchase of electricity, or Scope 2 emissions, account for the bulk of emissions (Onat et al., 2014). Following this Scope 3 emissions are the most plentiful, which represent indirect emissions such as waste disposal and transportation, with Scope 1 emissions, direct emissions for fuel usage, being the least impactful (Onat et al., 2014). Some literature also suggests rather than top-down carbon accounting, which starts from the production stage and sector scale, bottom-up carbon accounting, which starts from the consumption stage and the user scale, could be a useful tool for planners to properly apply carbon accounting (Tukker et al., 2020). This is because top-down approaches do not account for the outsourcing of production, making source 3 emissions deceivingly small (Tukker et al., 2020).

The three scopes in carbon accounting are not the optimal way to delineate emissions in the context of planning, however the principles and strengths can be applied and retooled as a planner needs (Wang & Chen, 2018). Some literature has used the three-scope system to derive a three-tier system for improving sector-based emissions throughout the city (Wang & Chen, 2018). The scope of this was limited geographically but did manage to identify new potentials for emission reductions (Wang & Chen, 2018). This limitation is important because carbon accounting and emission factors are very dependant on local factors (Chen et al., 2019). Some literature even suggests that rather than creating specific universal carbon accounting formulas, systems to create custom accounting formulas for specific contexts might be more appropriate (Chen et al., 2019).

In addition to this, some literature quantifies aspects of climate change emissions which, with some derivation could be used for creating emission factors which can simplify future emission quantifications (Nikravech et al., 2020). For example, knowing that 30-50% of produced food is wasted and 4.4 gigatonnes of CO_2e is emitted annually due to food waste, in conjunction with food produced in a region could be used to derive a food waste emissions factor (Nikravech et al., 2020). This emissions factor can then be used to determine how much food waste emissions a region produces even when the amount of food waste produced is unknown (Nikravech et al., 2020). That being said, this method is more akin to modelling than practical methods meaning it does not account for local context as well or falsely apply local context from one location to a wide scope (Lindon, 2014).

1.2.3 Behavioural Clusters

If looking at new techniques for behavioural climate change emissions, then another avenue to consider is how behaviours affect, compound and mitigate each other. If certain behaviours encourage other behaviours, then just as net-zero communities are able to implement multiple policies in a single mitigation solution, then the same could be done with said behaviours assuming said behaviours are climate improving behaviours.

There exists some research on how behaviours interact with each other in behavioural clusters, however this research does not pertain to environmental impact (Olds et al., 2017; Verger et al., 2009). This non-environmental research is focused on health, both physical and mental, and the habits related to them (Olds et al., 2017; Reedy et al., 2005; Verger et al., 2009; Williden et al., 2012). This research finds that behavioural clusters do form, however they do not always form in predictable manners (Olds et al., 2017; Verger et al., 2009; Williden et al., 2012). For example, one study on behaviour clusters hypothesized that depression causes other behaviours which negatively impact physical health and the results supported this logical hypothesis (Verger et al., 2009). However, another study on a similar topic with a similarly logical hypothesis, that healthy lifestyle behaviours cause one to make other healthy lifestyle choices, was not supported by the results (Olds et al., 2017). For example, one might similarly hypothesize that emission reducing behaviours cause one to make other emissions reducing behaviours, but behaviour research both supports and rebukes this (Olds et al., 2017; Verger et al., 2009). This could imply that one cannot just assume the most logical hypotheses and must specifically research how behaviour clusters as behaviour is not static across locations and populations.

Another note about this research is that, although not completely consistent throughout the research, behaviours related to negative behaviours, as in behaviours detrimental to physical or mental health, cluster more frequently than positive behaviours (Guo et al., 2020; Twisk & Senserrick, 2021; Verger et al., 2009). The literature has various independent explanations from low-sample size, to perception bias, however altogether this may suggest that there is something inherit to positive behaviours that cause them to cluster less often or vice versa (Reedy et al., 2005; Williden et al., 2012). However, that is all under the assumption that the contexts of health are the same as the context of climate behaviour and it is possible that climate-related behavioural clusters behave differently than health behaviours. In either case, to be certain of how behavioural clusters behave regarding emission reducing behaviours, further research is needed.

1.2.4 What are net-zero communities?

The general concept behind net-zero infrastructure is to reduce emissions to zero by first reducing emissions as low as possible, then offsetting said emissions through carbon absorbing methods (Bucking et al., 2015). One of the main aspects of net-zero is clean energy generation. From a carbon accounting stand point, clean energy produces no emissions, so if a household(s) is made more efficient such that it can be completely powered by clean energy it will also produce no emissions from any electrical needs in the household (Bucking et al., 2015). This is particularly relevant because this represents a significant portion of household emissions, especially if heating and cooling via electricity rather than by using fuels (Bucking et al., 2015). As such, there are two main aspects to reducing emissions in a net-zero building, reducing the need for electricity through better building materials and more efficient technology, and supplying needed electricity through clean energy (Bakhtavar et al., 2020; Kim et al., 2019; Gaiser & Stroeve, 2014; Vindel et al., 2019). This infrastructure began at the household scale with net-zero homes, but with improved technology and availability have been raised to the community scale and research has begun to theoretical scale these up to the city-scale (Bakhtavar et al., 2020; Fujimoto et al., 2017; Seto et al., 2021). In the context of planning, these net-zero homes/communities require a heavy consideration of local context to implement effectively rather than universal implementation solutions (Karunathilake et al., 2019; Zhivov et al., 2014).

There are many ways to improve net-zero implementation via improving energy efficiency, improving clean energy and improving the cost of net zero communities, with each categorization targeting one of the main aspects of net-zero implementation (Bakhtavar et al., 2020; Kim et al., 2019; Gaiser & Stroeve, 2014; Vindel et al., 2019). The first aspect of improving and implementing net-zero is better technology, such as heat pumps, and building materials with improved insulation capabilities (Ayyildiz & Erdogan, 2022). While better building materials can have other effects, including environmentally beneficial effects, when it comes to reducing emissions in a building, insulation is the main concern, where more advanced insulation provides less energy usage (Ayyildiz & Erdogan, 2022). However, more advanced building materials are less accessible and more expensive than traditional or better materials which are not top-of-the-line (Ayyildiz & Erdogan, 2022). From practical standpoint, especially with the volume of building materials used in a building, price is the most important factor followed by performance when choosing insulation (Ayyildiz & Erdogan, 2022).

The second is improving green energy. Location is an important factor because clean energy is at geographically locked at times and there is increased electricity loss over longer distances (Bakhtavar et al., 2020; Fujimoto et al., 2017; Karunathilake et al., 2019). In most places it is not realistic to achieve 100% of energy generation from clean energy due to this geographic limitation but in the context of Ontario this is less of a concern (Bakhtavar et al., 2020). This is of particular note in planning, which has some control over how close residencies are to clean energy and other geographic factors (Bakhtavar et al., 2020). If 100% of energy generated was clean energy then 100% of energy based emissions would be reduced as clean energy does not produce emissions while producing energy, therefore the main concern in clean energy research is how to improve output such that 100% clean energy becomes closer to reality (Shandiz et al., 2021; Young & Brans, 2017). In recent research this has be done through better planning, improved local storage and collaboration and a better understanding of clean energy including when to use which method of clean energy generation (Bakhtavar et al., 2020; Fujimoto et al., 2017; Karunathilake et al., 2019).

With the effectiveness of net-zero explored, it is also worth considering other considerations for improving net-zero rather than just technological considerations. There are many ways the effectiveness of a net-zero community can be altered but the most important factor to consider are local contexts (Karunathilake et al., 2019; Zhivov et al., 2014). For example, in some communities, where the environment is the greater concern, wind power is a great renewable option, but for a community which values economics, landfill gas is a better option (Karunathilake et al., 2019). Additionally, even though hydro power was found to always be a good choice, some places do not have access to hydro power (Karunathilake et al., 2019). Seeing as local context is so important, in the local context of Ontario, there is only one existing net-zero community (Williams, 2018). There is however no, non-theoretical research on it because the first phase of it was only recently completed (Sifton Corporation, 2019). There is however theoretical research regarding economic modelling of the community done when it first began construction (Bucking & Cotton, 2015).

Additionally, research shows that when implementing net-zero communities, community participation is a large factor in motivating decision makers and planners (Young & Brans, 2017). Despite this, social factors, along with energy resilience are often overlooked in planning for net-zero communities (Shandiz et al., 2021). The implication is that even though net-zero communities are proven effective, due to higher implementation cost and the nature of planning, in that planning is done for the public, there must be public demand for net-zero communities (Shandiz et al., 2021). This implies an importance of understanding climate action at the local scale and user-based approaches as planners can use this understanding to increase the need and value of net-zero communities.

Speaking to the importance of scale, it is important to consider the effect of different scales of net-zero and which scale research and implementation is best conducted at. First, considering the smaller-scale net-zero home, while some of the basic characteristics are the same, such as a reduction in emissions, the value of said characteristics does not scale linearly (Thompson & Krarti, 2021). For example, the cost of outfitting a net zero community with solar panels is 31% lower than outfitting the same amount of individual, net-zero houses (Thompson & Krarti, 2021). It should be noted that this study was done in a location where solar panels are more efficient, so in a Canadian context this efficiency is likely lower (Thompson & Krarti, 2021).

Meanwhile, when increasing scale to a net-zero city, problems arise (Seto et al., 2021; Shandez et al., 2021; Williams, 2018). The first is that no net-zero cities currently exist: they are currently just theoretical (Seto et al., 2021). The second is that the increased complexity creates additional problems even in a theoretical sense (Seto et al., 2021). Not only are there more factors to consider but there are also factors which are not within the city that affect the emissions within the city (Chen et al, 2019; Seto et al., 2021). Due to these additional and complex factors, proper net-zero cannot be achieved without carbon sequestration (Seto et al., 2021).

Therefore, the community scale of net-zero is optimal. First, they exist, therefore can be studied in a real-world setting (Bucking & Cotton, 2015). Second, smaller scales are generally less complex than working at larger scales, especially in the urban context, therefore is less likely to contain lurking variables (Seto et al., 2021). Third, they are more cost effective than other scales (Bucking & Cotton, 2015; Kim et al., 2019). Finally, from a policy perspective, the community scale strikes a balance between the complexity of a larger scope and the increasing resources needed to design policy for smaller scales, the reason for this being that a policy tailored for a hundred communities is less taxing than a policy tailored for a thousand homes (Fujimoto et al., 2017; Larsen & Hertwich, 2009; Tukker et al., 2020). While this may change over time and in an implementation context, for research, net-zero communities have high potential.

1.2.5 Study Framework

After examining the literature and the gaps in the literature, a clear framework for a research study can be formed. In this case, when refined, the intersection of environmental protection, planning and behaviour under a quantitative and practical lens provides a unique study environment which is consistent with ideas in current literature while exploring gaps in the literature. The refinement of these concepts based on literature reviewed will be discussed and distilled into the working framework used in the design and implementation of the entire study.

Planners have many tools and strategies which can improve climate change (Karunathilake et al., 2019; Lau, 2022; Schifman et al., 2017; Zhivov et al., 2014). These strategies not only have the ability to make direct change, but also indirect change, a theme which is reflected in the physical versus behavioural themes of the entire study structure. With the goal being climate change mitigation, the metric by which this is measured is minimizing greenhouse gas emissions as this will help meet global climate change targets outlined by the United Nations (Streimikiene & Volochovic, 2011; Wynes et al., 2018). Therefore, the metric by which this study measures and compares environmental impact is greenhouse gas emissions, specifically in weight of carbon dioxide equivalent per unit of time [weight of CO_2e/time]. The reasons this is the optimal metric of environmental impact in this context is that this is a globally recognized metric of environmental impact, which makes this output versatile and practical, reflecting the field of planning (Streimikiene & Volochovic, 2011; Wynes et al., 2018).

Planners can reduce emissions by implementing emission-reducing policies. One problem is in efficiency, if a single policy aims to target only a single aspect of climate change mitigation, then there will be a bottleneck on the potential of planners to mitigate climate change due to the time to develop and implement policy (Mai & Hoffman, 2012). Net-zero offers a solution to this as it is a planning solution that can address many aspects of climate change mitigation at once (Elizondo et al., 2017; Seto et al., 2021). This is because net-zero communities are a solution which uses multiple climate change solutions to reduce active emission to zero (Elizondo et al., 2017; Seto et al., 2021). For example, a planner can implement policy to encourage house retrofitting, which improves insulation and reduces heating needed (Ayylidiz & Erdogan, 2022). A planner can also implement clean energy policies which effectively nullify emissions from energy generation however is limited in its capacity and geography (Shandiz et al., 2021). However, when planners zone for net-zero communities, they implement both these policies at once, which not only is more efficient, but also compounds the effectiveness of the two methods (Elizondo et al., 2017; Seto et al., 2021).

The issue that comes up in net-zero research is that net-zero is not realistically achievable at the city scale or beyond, or at least not true net-zero (Shandiz et al., 2021; Young & Brans, 2017). This is because of the scalability of clean energy and the high costs of the technology required for net-zero (Shandiz et al., 2021; Young & Brans, 2017). Therefore, although net-zero would optimally be implemented at a global scale, this is not possible. With the effectiveness of net-zero having a ceiling and literature indicating the need for a diversification in climate solution rather than just technology, planners need solutions which can be implemented at a higher scale that are similarly effective to net-zero communities. This can be addressed by a gap in the literature.

Behavioural research into climate change mitigation is less common than technological improvements when it comes to quantifiable results (Johansson, 2009; Kromer er al., 2010; Lee & Lee, 2014; Morrow et al., 2010; Streimikiene & Volochovic, 2011; Wynes et al., 2018). Not only is behavioural research less common under a quantitative lens but is also has a methodological gap as current behavioural research is almost entirely using predictions and modelling rather than sampling as a method (Dietz et al., 2009). This is specifically relevant to planning which is an applicative, practical field where local context is important in many of the decisions (Jones & Kammen, 2011; Larsen & Hertwich, 2009; Reames, 2016). Behavioral research is more scalable because there are few barriers to implementing behavioural affecting interventions (Girod et al., 2014; Reames, 2016; Streimikiene & Volochovic, 2011). Everybody exhibits some sort of behaviour, and behaviour affecting policy while potentially less viable, is less taxing in a monetary and temporal sense (Girod et al., 2014). And, in conjunction with the literature gap on emission affecting behavioural clusters, has the potential to be similarly efficient as net-zero communities (Johansson, 2009; Kromer er al., 2010; Lee & Lee, 2014; Morrow et al., 2010; Streimikiene & Volochovic, 2011; Wynes et al., 2018). For behavioural clusters, the metric by which they are measured will be two-fold. First is if behaviour clusters can be identified. This metric is simply whether or not any given behaviour clusters exist. If they do exist, then the second metric is how potent each behaviour cluster is. This metric is based on how related each behaviour in the cluster is, which in turn will be based off of how similarly these behaviours affect greenhouse gas emissions. (Twisk & Senserrick, 2021)

One aspect of the study and literature that has yet to be discussed is the methodology. To find the true value of behavioural climate solutions in planning, especially when comparing to technological solutions, these solutions must be numerically quantified. The problem in literature is that quantification methods are centered around technological quantification, which measures output of the technology, or uses predictive or modelling methods to determine the potential of behavioural solutions (Higgins et al., 2011; Niamir, 2020). For an applicative field like planning which relies heavily on local context, this can be an issue as modelling can remove the nuance of local context (Jones & Kammen, 2011; Larsen & Hertwich, 2009; Niamir, 2020; Reames, 2016). Therefore, to fill a literature gap and to best suit a study which compares behaviour to physical interventions a sample in a unique geographic context is optimal. How to do this despite the methodological gap is to take aspects of other emissions quantification methods and combining them with principles and goals of planning practice. The results of the sampling methods can then be compared to modelled results to compare the efficacy, accuracy and merits to both approaches.

One final issue that only comes up when looking at the intersection of these topics comes when looking at net-zero and emissions reduced by behavioural interventions. While the two address different aspects of emissions the two are difficult to compare. Because net-zero, as the name implies, reduces or aims to reduce emissions to zero, trying to compare it to other reduction methods is logistically difficult. Any other method will appear mathematically ineffective when comparing emissions. This is the reason net-zero research focuses on more efficient and cost-effective ways to implement net-zero rather than the emissions net-zero produce, because again, that number is effectively zero emissions (Shandiz et al., 2021; Young & Brans, 2017). Therefore, to compare net-zero properly either a different metric must be chosen, such as cost-effectiveness, or a less standard method of quantifying emissions must be used. The second is preferable as greenhouse gas emissions are the standard measure of climate change impact, and the measure of impact outline in this framework (Streimikiene & Volochovic, 2011; Wynes et al., 2018).

Overall, the goal is to find how the greenhouse gas emissions reduced by behavioural interventions numerically compare to reductions from physical improvements of a net-zero communities to find whether these interventions are more, less or equally as effective. Whether or not they are more or less effective is technically, irrelevant as literature indicates the need for behavioural methods of emission reductions, and in either case additional behavioural research should aim to improve the efficiency of these methods. Knowing how they compare does change how one might improve behavioural efficiency, how one might implement behavioural methods of emission reductions and how they can work with and against traditional methods of reducing emissions. In other words, this knowledge feeds into the practical application of behaviour to reduce emissions rather than just theoretical research. To further the applicative purposes, another secondary goal is to better understand what behaviours are common amongst each other, or rather how do environmental behaviours cluster. This will assist in improving the efficiency of behavioural methods for applicative purposes by letting users target multiple emission reducing behaviours at once.

Chapter 2 – Methodology

2.1 Research Questions and Objectives

Studies which are able to directly compare carbon emissions reduced by technological improvements to emissions reduced through other methods, such as changes in behaviour, are uncommon. In a study like this, it is key that non-technological methods are quantified so that this direct comparison is possible. It is also important to understand how planners can apply the knowledge of these behaviours in their practice. The underexplored nature of questions linking behaviour and emissions presents additional study opportunities.

The primary research question for this study is "How do choices in behaviour alter the emissions a household produces". This theme will be explored throughout every chapter and is the lens that will focus the subjects covered in each chapter. These choices will be evaluated both quantitatively and qualitatively and specifically consider how they relate to how emissions are affected by better technologies. Additionally, there are two secondary questions in "How effective are net-zero communities in reducing GHG emissions" and "Are there common behaviours that indicate higher or lower emissions". The first secondary question helps give credence to this research, making it comparable to past emissions research on net-zero homes and reinforcing results, and will be the focus of Chapter 3. The second of the two questions is an auxiliary concern which the research is not designed to answer but may provide some insight on application methods for the other findings, and will be covered in Chapter 4. These three questions lead into the following objectives:

How do choices in behaviour alter the emissions a household produces

1) To quantify the emission increases/decreases as a result of household choices.
2) To determine how much behavioural emissions reductions can influence household emissions compared to physical emissions reductions.

Are there common behaviours that indicate higher or lower emissions

3) To determine if there are patterns in behaviour among people with similar emissions profiles.

2.2 Quantifying in the Context of Net-zero

As noted in Chapter 1, there is a persistent issue in comparing net-zero to other emission reducing climate solutions. In summary, with net-zero having few emissions to no emissions, depending on the methodology used to analyze them, other emissions reductions cannot compare. Even when looking at emissions before offsets, one-to-one comparisons are difficult because so many emissions sources produce no emissions. The issue with net-zero comes from scalability and cost which is why research regarding net-zero concerns those issues, meaning although net-zero emissions are concerned with emissions, that is not the metric they are measured by (Shandiz et al., 2021; Young & Brans, 2017). The issue is that emissions are the metric by which most other methods of emissions reductions are measured by, making comparisons to net-zero difficult (Streimikiene & Volochovic, 2011; Wynes et al., 2018).

There are two solutions. Perhaps the simplest is using cost or cost per emission reduced as a metric rather than greenhouse gas emissions. The reason why this is not optimal for this intersection of topics is the behavioural aspect. In literature, some definitions of behavioural emissions reductions are emissions that have no associated cost, which is the same issue with net-zero regarding cost rather than emissions (Streimikiene & Volochovic, 2011). Therefore, to properly compare the two net-zero needs an associated emissions value and/or behavioural emissions reductions need an associated cost. The way this can be done is breaking down why net-zero is net-zero and/or why behaviour has no cost.

For behaviour, this is reasoned to be that to change one's behaviour has no cost associated with it and therefore the lack of cost is innate (Streimikiene, D. & Volochovic). This is a fallacy, because some behaviour research shows that there is a cost, however this cost can also be a negative cost, or rather it can be profitable to change a behaviour (Wynes et al., 2018). For example, driving less will cause an individual to have more money than they would if they did not change their behaviour (Chapman, 2007). This means that there are layers of complexity to cost and behaviour some of which have not even been explored to the lack of behavioural intervention research with quantitative measures (Reames, 2016).

Much simpler though is net-zero which as noted in the literature is greatly pushed towards net-zero by clean energy (Karunathilake et al., 2019). This same clean energy is also a barrier to large-scale implementation (Young & Brans, 2017). In the context of Ontario, clean energy is already used at a relatively high ratio (ECCC, 2021). These three facts combined together create a methodology for assigning emission value to net-zero for comparisons. If electricity usage from a net-zero home has the emissions factor of local energy generation applied to it will be as if the clean energy aspect is removed. While this arguably removes the value of net-zero, because of the fact that clean energy cannot be scaled up, the removal of clean energy makes this more realistic. And because of the geographic context of Ontario, it will not be completely removed as Ontario uses a significant amount of clean energy (ECCC, 2021). Therefore, normalized emissions in an Ontario net-zero community could in some respects be considered a simulation of how net-zero cities compare to behavioural emissions reductions. At the very least, removing clean energy from emissions calculations puts net-zero and behaviour in the same unit of measurement which solves the issue at hand.

In summary, the most realistic solution to the issue of net-zero comparisons is removing clean energy from the emissions calculations by applying local emissions factors to net-zero electricity usage. As such, this study will implement this method of emission normalization, while also analysing the results without this normalization for a clear picture of the effects of net-zero versus other technological improvements.

2.3 Methodological Reasoning

The methods for this study were taken from other methods of practical emissions quantification, or quantification methods that use samples to determine emission rather than predictive models. The value of monitoring is that it is accurate, especially at smaller scales, which allows local context to be properly understood, assuming this is directly measured (Lindon, 2014). It is however inconsistent and has more onus on the data collection because not all metrics can be directly measured (Larazzi et al., 2022; Lindon, 2014). For example, electricity usage for a home can be directly measured, however exactly how much of that electricity usage is due to appliances cannot be measured unless specific technology has been installed at the homeowner's discretion and even then has gaps in data (Fujimoto et al., 2014; Larazzi et al., 2022). In many cases, appliance electricity usage must be calculated or estimated based on how many times each appliance was used and its energy efficiency, which relies on assumptions or self-reporting (Fujimoto et al., 2014). Meanwhile, model-based methods of quantification can do anything monitoring can do however requires enough data to create a robust enough model to match this (Niamir, 2020). With there not being any data on net-zero communities in Ontario, a confident model could not be made at this time, defaulting to traditional monitoring and surveying methods (Williams, 2018).

The primary inspiration was carbon accounting, which splits emissions into three categories of emissions, direct scope 1 emissions, indirect scope 2 emissions, and asset-based scope 3 emissions, and calculates each for a business (Chen et al., 2019; Wang & Chen, 2018). The problem with carbon accounting is the 3 scopes are not appropriate for planning and household emissions because there are few scope 1 emissions and scope 3 emissions do not make sense in a household context (Wang & Chen, 2018). The value of carbon accounting to planning is that it has a good organization and categorization structure that can be applied to household categories of emissions for a better understanding of the affecting factors (Wang & Chen, 2018). Additionally, the methods of carbon accounting, using emissions factors to convert emission sources to a single unit, is useful when the purpose of the study is to make comparisons as it makes the different categories directly comparable. Therefore, instead of the three scopes of carbon accounting, emissions were categorized based on source, a more appropriate categorization when using these results for planning application.

The choice of geographic context is valuable because it has high potential for net-zero implementation. Currently, the study site is the only net-zero community in Ontario, coupled with the high potential for clean energy in the province means that there can be more net-zero communities which are effective and truly net-zero (ECCC, 2021; Williams; 2018). Arguably, a context such as Ontario, with access to technological improvements, high clean energy potential, relatively lower population and a demand for improved environmental action is where the higher scale net-zero city is most realistically achievable (Seto et al., 2021).

Other planning literature which used sampling to calculate environmental impact usually did so in collaboration with other companies as to directly monitor electricity/water usage or use records of direct monitoring (Shahmohammmadi et al., 2019; Streimikiene, D. & Volochovic, 2011). This provides the most accurate results which are robust and can be used for scaling up calculations and to develop models (Shahmohammmadi et al., 2019). Management companies for the study sites were reached out to so that arrangements for this could be made however none responded, therefore calculated emissions had to be based on reported emissions. This caused reduced accuracy and further limitations related to calculating statistical significance, which will be discussed in further detail later in this chapter.

2.4 Scale of Research and Potential Effects

An important piece of background is figuring out what scale such research should be done at and why. While future research can be scaled up and down as needed, a preliminary study must maximize the chances of an observable effect. To do this, the different components of the research question can be analyzed individually then as a whole to determine the scale at which this kind of research is most suited for. As noted in Chapter 1, the primary components of this research question are behaviour, emissions reductions and green infrastructure. How each of these components can be applied in a planning aspect will be analysed first individually then as a whole to determine the optimal scale for this study.

When it comes to subjects such as behaviour and choice it is more natural to start on a small-scale and work up in the context of research (Mai & Hoffman, 2012). That is because behaviour is innately on a small scale, which can be generalized into larger scales only after knowing many individuals partake in such behaviour (Wynes et al., 2018). That being said, the individual scale is too small a scale for the field of planning; you cannot design or plan a city around how one individual will interact with the space around them; generalization is needed or there will be too many facets to consider (Elizondo et al., 2017). Building on this, larger-scale behaviour trends while not appropriate as a starting point, can still be valuable when applying to planning, specifically in the creation of planning policies, because policies are innately large-scale decisions trying to effect change on a smaller change (Girod et al., 2017). However, specifically in the context of planning, local context is one of the most important factors in any planning decision (Jones & Kammen, 2011; Larsen & Hertwich, 2009; Reames, 2016). Therefore, while behavioural research is more suited for a smaller-scale, mid-scale behavioural research can be used and applied, especially in a planning context.

For emissions reductions, the scale it is researched is less pertinent. It is possible to start small scale and work up, such as surveying each household's electricity usage then summing it for the whole city, or if the methods are available, it is possible to start at a large scale, such as using the electric companies' total produced electricity (Streimikiene & Volochovic, 2011). In both cases the same result would be reached, therefore for emissions reduction, the more important question to ask when determining scale is the context in which is being applied. In the context of this study, this is ultimately a mid to large scale as mid-scale is the scale most planning is done and because policies and climate summits care about large-scale emissions at the national/international level (Elizondo et al., 2017; Wynes et al., 2018). To summarize, emissions reductions are an adaptable sector of research which can be applied to any scale, however larger-scale emissions reductions are the ultimate goal, including in planning.

Finally, net-zero is an interesting field of research because in a residential context, practically speaking it only exists on a small-scale, however there is theoretical research about large-scale net-zero (Seto et al., 2021). The largest scale to which net-zero exists is the community scale (Seto et al., 2021). While some other forms of green infrastructure exist at larger scales, such as renewable energy, even those do not scale to the highest scales (i.e. national/international scale) (Elizondo et al., 2017; Seto et al., 2021; Shandiz et al., 2021). In terms of application, planning is a practical field and as such prefers realistic and achievable results over idealistic or theoretical potential (Bakhtavar et al., 2020). That, combined with the fact that net-zero infrastructure cannot always be realistically applied to mid to large scales at this time results in the conclusion that when applying net-zero in a practical context, only small-scales are possible (Elizondo et al., 2017; Seto et al., 2021; Shandiz et al., 2021). That being said, the smallest scale (i.e. individual scale) is an inappropriate scale to apply net-zero as a net-zero person does not make sense as a concept. This is because for a person to be net-zero you must take into account all their emissions, including emissions from the home, making household the smallest logical concept of net-zero.

Synthesizing these three components together leads to a rather simple conclusion. Even though the emissions component calls for a larger scale study, it is still usable in a smaller scale and the other two components prefer/require a small scale to be effective. Therefore, a study on this topic should be done on a small-scale, but because of the green infrastructure, and by extension net zero, component, this must be at either a household or community scale. For selecting between these two scales, previous literature was used to come to a reasonable conclusion. Based on literature gaps for research at the community-scale, partially due to the rarity of net-zero communities, this is the scale that would be the most beneficial to academia as a whole (Bakhtavar et al., 2020; Elizondo et al., 2017).

2.5 Site Selection and Context

In terms of site selection, there is not much choice as there is a single net-zero community in the geographic research gap of Ontario (Sifton Corporation, 2019). This community is named the West5 community and is set of 53 townhouses which are 2-3 bedrooms and completed construction in 2018 (Sifton Corporation, 2019). This community is technically only the first part of a much larger community consisting of townhomes, full-size homes, a retirement home, apartments, amenities/entertainment, offices/work spaces and greenspaces/parks (Sifton Corporation, 2019). This community is located on the outskirts of London, Ontario, and these community was designed and planned from the ground up: no retrofitting or previous infrastructure existed or was used (Sifton Corporation, 2019). This had various benefits that may not be transferable to most planning contexts as there was not existing zoning and infrastructure to plan around and no obstacles to making the community walkable and relatively accessible.

To achieve net zero, this community employed a few strategies. First, is a dedicated renewable energy power grid generated via solar panels on every building and on other infrastructure such as parking areas (Natural Resources Canada, 2018). Solar power can be inconsistent however, so the community utilizes improves energy transfer, storage and sharing, better insulation, improved heating and cooling and high efficiency technology to lower electricity demand and usage throughout the community (Natural Resources Canada, 2018).

For the control, a community which was infrastructurally similar to the net-zero townhomes was needed. Some key infrastructural points of note were year of construction, number of homes, size of homes, distance to amenities and geographic location. The community found was also in London, consisted of 87 three-bedroom homes and, based on satellite imagery, completed construction in 2016 so the level of technology available was relatively close to that of the net-zero home.

2.6 Methodology

To answer the research questions, two communities were surveyed. First, was the West5 community in London: a net-zero community constructed in 2018 with 53 townhouses ranging from 2 room units to 3 room units. The second control community was the Towns in Hyde Park community in London: a regular townhouse complex constructed in 2016 with 87 homes that have 3 bedrooms. The survey was designed to collect data on all aspects of each household's emissions profile. Analysis post data-collection was based on principles and techniques of carbon accounting, which is to say responses were converted into quantitative emissions then sorted into broad categories. The full survey can be found in "Appendix 3: Complete Survey". First, the survey asked about attitudes towards climate change to help evaluate behavioural emissions reductions. This was done using 15 climate change related questions on a 5-point Likert scale, which was averaged out to get a general idea of where the household stood on climate change. Outliers were also analyzed for more in-depth behavioural analysis.

Next the survey asked about energy usage by asking monthly natural gas usage, electricity usage to estimate emissions in the entire household, and more specific questions related to light usage, appliance usage, and temperature settings to breakdown the general emissions into more specific categories. Electricity usage was be converted to emissions estimations using provincial emissions factors gathered from secondary data, primarily the National Inventory Report.

Furthermore, the survey asked questions regarding waste and food produced. Respondents were asked to estimate the amount of waste, recycling and compost produced in volume, which was converted to weight using average garbage density and then converted into emissions estimates via National Inventory Report emissions factors. Respondents were also asked to estimate how much of their waste was food waste and how much food was purchased local and/or organic. These were used to estimate additional emissions form food waste and emission reductions from local food purchases.

Finally, the survey asked questions regarding transportation, specifically distance travelled via motorized vehicle and the make and model of said vehicles. This was converted to emissions data by multiplying the distance travelled by the fuel efficiency of their vehicle and emissions factors of the fuel used, taken from the National Inventory Report. This emissions data was analyzed using statistical analysis where possible, but when impossible due to questionable accuracy, was only compared to control data.

The number of responses received from the net-zero community was 8 out of 53 while the control community received only 2 responses. To accommodate the low response rate from the control, secondary data relating to local, provincial and national emissions data was collected to compare to the results from the net-zero community. Local, city-wide averages were prioritized when available, with provincial averages used if local averages were unavailable, and national averages used as a last resort. Local stats came primarily from the City of London, while provincial and national averages were primarily from Stats Canada, with some supplementary statistics taken from reputable news outlets. This data was analyzed the same way as the survey responses, as in they were converted to average emissions produced annually with relevant emissions factors if that was not the unit the data was found in.

2.7 Limitations

This study had limitations, some which were built-in to the design of the study and were kept in careful consideration throughout, and some of which were not considered but encountered throughout the methods and thought to have an effect on the results. One limitation which could not be circumvented at the time of the study was lack of suitable study communities. There is a single net-zero community in Ontario leaving no other options and introducing many unknown biases which would be specific to this geographic context. But as time goes on and more green infrastructure is introduced in the province, more study sites become available.

Another unavoidable limitation is response bias. Building on the previous limitation, the low population of the community limited the pool of available data, which resulted in the entire community being sampled to ensure enough responses were received to create a usable dataset. Essentially, the sample was very far from random, and it is entirely possible that because of response bias that emission results were lower than average due to positive response bias (i.e. those with lower emissions were more inclined to respond).

A limitation which arose mid-study was the lack of experimental control data. While secondary control data was used, it is not as precise or comparable to experimental sample data. This is in part due to mismatching scale (i.e. community scale compared to provincial/federal data), wider variation (ex. data from any size home built in any year rather than similar control houses) and differing levels of data recency.

One final limitation which was built into the study design was the inability to test for statistical significance in some cases. The reason the study was designed this was to improve response rate in emission categories which were deemed less effective based on past literature and knowledge. More specifically, in some cases respondents were instructed they could estimate an emission category or abstain from responding to any given question. Responses in these categories must have this taken into consideration when being analyzed.

Chapter 3 – Better Technology Versus Better Behaviour: What Are the Benefits of Net-Zero

3.1 Abstract

While net-zero homes effectively reduce greenhouse gas emissions, there is a need for alternate climate change solutions that are cheaper and realistically achievable for a wide population. As such, this study aims to compare greenhouse gas emission reductions as a result of physical improvements against those as a result of changes in behaviour, specifically in the context of net-zero communities. After surveying 8 out of 53 households in Ontario's first net-zero community it was found that when compared to houses with a similar local context, net-zero homes produced 6.89 fewer equivalent tonnes of CO_2 per year. Of this 6.89 tonnes/household/year, 67.5% of reductions were attributed to physical sources while the remaining 32.5% of reductions were attributed to better behaviour. The primary source of physical reductions was clean energy while the primary source of behavioural reductions was reduced car travel, which accounted for 25.0% and 34.4% of total reductions respectively. While reduced car travel was inherit to this net-zero community, this is not inherent to net-zero communities and therefore this method of reductions could be implemented separately. Practically speaking, this means while less effective, behavioural emissions reductions can be used both alternatively and in conjunction with physical methods of emissions reduction. Future research should focus on improving methodology and definitions for emission reducing physical and behavioural interventions. Future research could also apply these ideas and principles to other contexts, such as workplaces or sociological groups.

3.2 Introduction

The most prominent form of emissions reductions, in literature and in practice, are improving technologies (Shandiz et al., 2021). Every field has constantly improving technologies which in many cases reduce emissions, whether intentional or not (Shahmohammadi et al., 2017 ; Shandiz et al., 2021). Planning is no exception, and in a residential planning aspect, a prime example of this are net-zero homes. The main problems with net-zero are limited scalability and high-cost which make is hard to implement over a wide population (Shandiz et al., 2021; Young & Brans, 2017). Due to the scale of climate change, literature indicates a need for a diverse set of solutions including both improvements to technology and improvements to behaviour, which emphasizes the scalability issue of net-zero (Shandiz et al., 2021; Young & Brans, 2017). There is also a question of how much of zero emissions in net-zero infrastructure is due to clean energy and other technologies and how much is due to other factors (Shandiz et al., 2021). While all emissions reductions are being attributed to just the improved technology, if the new setting is causing residents to change their emissions patterns in other ways it would be inaccurate to count that as a result of technology.

Overall, behaviour represents a potentially more cost efficient and widely applicable method of reducing emissions by planners (Streimikiene & Volochovic, 2011; Wynes et al., 2018). Therefore, it is necessary to evaluate how effective behaviour can be in comparison to technology. However, behaviour is complex and to fully understand it is difficult to understand and to quantify but can provide positive effects if this knowledge is applied to policy making (Olds et al., 2017; Wynes et al., 2018). The goal of this chapter is to provide evidence for/against the proliferation of net-zero communities and/or behavioural methods of emissions reductions and how physical and behavioural interventions compare and contrast one another.

3.3 Physical and Behavioural Emissions Reductions

3.3.1 Defining Physical and Behavioural Emissions Reductions

The crux of this study is defining what behavioural emissions reductions are and how they differ from physical emissions reduction. Because literature is lacking on the subject of how choices quantifiably affect emissions, "behavioural emissions reductions" is not a term that is pre-existing or pre-defined, therefore must be defined here. While other studies look at how behaviour affects emissions, generally they look at an individual behaviour or an individual emission source, not a group of behaviours on a group of emission sources (Johansson, 2009; Shahmohammadi et al., 2019; Wynes et al., 2018). At its most basic definition, physical emissions reductions, which will sometimes be referred to as "PERs" for brevity, are emissions reductions that come from improved technology and/or infrastructure, while behavioural emissions reductions, or "BERs", come from personal choices. But, to fully understand what is meant by behavioural emissions reductions, simply saying BERs are as a result of a choice is not specific enough. Ultimately, anything could be boiled down to a choice and even some literature categorizes what could be better defined as improved technology as improved behaviour (Dietz et al., 2009). For example, fully electric vehicles could be considered both a physical and behavioural emissions reductions based on the previous definition. They are an improved technology on gas vehicles, but also requires someone to choose that as their vehicle. This highlights why this definition must be specified further now, as to not cause confusion, methodological errors or misclassification later.

Before further defining and reasoning for this definition are the assumptions for these definitions. First is that these two definitions are binary. That is to say, existing in one category automatically disqualifies it as the other. This also means there are no other possible classifications. As such the definition must accommodate this assumption. This is for academic reasons and methodological reasons; because this is a cursory study into a rather unexplored topic, it makes sense to keep these categories distinct until they are further understood, after which studies can be done with more hybrid or additional classifications of emission reductions. While both literature and logic contradict this rule, it was considered a necessity in simplifying the study design (Chapman, 2007; Dietz et al., 2009; Streimikiene & Volochovic, 2011). Second, is an assumption that an emission source stays static over time, as in it does not switch from physical to behavioural emissions reductions and vice versa. While this might also be unrealistic when applied to the real world, especially depending on your definition for physical and behavioural reductions, this follows the same reasoning as the binary definition, to simplify the study. Finally, is the assumption that a reduced emissions can only ever be from one source. This too is unrealistic because one can, for example, reduce heating needed physically by improving insulation or behaviourally by setting the heat to be lower. The reason for this is that previous literature was unable to separate physical from behavioural due to measuring only output (Streimikiene, 2015). Therefore, to properly differentiate emissions must be considered at the source. To decide which took priority, the context of the study was considered, where if something inherit to the design and nature of net-zero infrastructure could reduce emissions, it was prioritized as physical reductions, while in all other cases behavioural was prioritized.

With these assumptions, how physical and behavioural emissions reductions are differentiated can finally be explored. Apart from what was mentioned earlier, ala the simple definitions, one rule was used to decide if choosing a technology was a physical or behavioural reduction. If the technology is widely available and realistically achievable by the average person, then choosing a technology is considered a physical reduction, as there is little choice. For example, improving the building envelope to reduce heating and cooling costs can be done relatively easily and the materials are available at any hardware store (Ayylidiz & Erdogan, 2022). Meanwhile, if technology is not widely available due to cost or rarity, such as electric vehicles, or if is unrealistic for it to be applied at any scale, such as fully renewable energy, then a decision must be made to implement that intervention or spend money on a different, potentially more cost-effective solutions. In the few remaining cases where the simple definitions and the aforementioned rule were insufficient to define a category, mainly when a change to behaviour was caused by improved technology or infrastructure, such as a new highway resulting in less vehicle usage, these were deferred to as behavioural reductions partially for simplicity and partially because these do not eliminate the choices in the behaviour and sometimes even introduce more choices.

3.4 Statistical Analysis of Physical Versus Behaviour

Generally, statistical analyses assume a few things, particularly randomness, homogeneity and a normal distribution (Lindon, 2014). These assumptions are not applicable to the study site because it is not a randomly selected site, it is chosen with purpose: that it performs better than the average household (Bakhtavar et al., 2020). Also due to the numerical nature of net-zero and the nature of emissions, for the most part being unable to pass below zero, this dataset would be further skewed and produce non-normal variances. As such traditional statistical analyses such as the t-test would be inappropriate to apply. However, a t-test would be valuable because it can compare how a study site performs in comparison to a control site.

Bayesian analyses address this by adjusting these assumptions so that they can better fit the study site (Lindon, 2014). In this case, it is almost a certainty that the net-zero performs significantly better in emissions categories than a regular community, based on logic and based on literature (Bakhtavar et al., 2020). It can also be surmised that this distribution will ultimately be right skewed as previously stated because of the numerical and applicable properties of carbon emissions in that there are very few ways to have negative carbon emissions (Bakhtavar et al., 2020; Bucking & Cotton, 2015). The Bayesian model factors in these assumptions when processing and comparing the observation points (Lindon, 2014). There are potential weaknesses if previous research cannot fully agree or does not fully detail how skewed this variable would be, or how other assumptions are shifted, however in the case were there is significant variation such as this, Bayesian is a better fit (Lindon, 2014). Therefore, a Bayesian t-test can better represent the nature of emissions data in a net-zero community as it removes the assumptions of traditional t-tests which do not fit the study context.

3.5 Methods

3.5.1 Study Context

Based on the realistically applicable scales of net-zero households or net-zero communities, there is a limited pool of potential study sites, especially in the local setting of Ontario (Williams, 2018). At the community level there is only one net-zero community in the entire province at the time of the study, located in London, Ontario

(Williams, 2018). The community is a long-term project which is creating an entire net-zero district of the city, with the net-zero community in question being only the first part and was constructed in 2018 (Sifton Corporation, 2019). This community, called the West-5 townhouses, is made up of 53 townhouses which have various floorplans which have either 2 or 3 bedrooms (Sifton Corporation, 2019).

The city of London has fewer emissions than the provincial average, the province in turn having greater emissions than the national average (City of London, 2020; ECCC, 2021). Comparing London directly to the national average, London households emit 9.3 tonnes CO_2e /year, which is almost equal to the national average of 9.38 tonnes CO_2e annually (City of London, 2020; ECCC, 2021). In the global context London, and Canada as a whole have a higher emissions per capita than the global average (Environmental Climate Change Canada, 2022). These statistics highlight a few key factors. First, London is a good example of an average Canadian household making it an excellent location for household-based emissions studies. Second, there is potential for significant reductions both relatively speaking and absolutely speaking. The study was conducted in late 2021 and early 2022 making most of the secondary data analyzed recent within 5 years.

3.5.2 Data collection and analysis

The study was conducted via mail back survey and, at a later date, door-to-door and online surveys which were identical to the mail-back and only issued to improve response rates. The full surveys can be found in "Appendix 3: Complete Survey" but in short, these surveys were designed to collect numeric information on a broad range of topics which affect emissions so they can be used to quantify emissions. These responses are not the most accurate as questions were formed in a way to lower survey completion time and in turn improve response rate, such as asking for estimates or non-scientific units of measurement (ex. bins of garbage opposed to kg or garbage). This was augmented by requesting specific numbers for aspects which, based on literature, were expected to have a greater affect on emissions so that accurate statistic analysis could be conducted.

While a control community was chosen and surveyed, response rate was insufficient for both a formal and informal analysis. Therefore, to complete the analyses, rather than a control community, control statistics were taken from a variety of reputable sources. This mainly includes statistics from government organizations such as StatsCan), reputable non-profits and other research papers. As the government organizations implies, this was taken from a variety of scales including local, provincial and national, however local was prioritized as it would be the most accurate, and national was taken as a last resort if more specific/accurate statistics could not be found.

Using the survey responses, each emission source was converted from the reported unit to tonnes CO_2e /household/year. This was done by using an emissions factor listed in previous research or derived from previous research or statistics. For example, the National Inventory Report lists emissions factors for gas vehicles, burning natural gas and certain types of garbage, among others (ECCC, 2021). If the natural gas used is multiplied by the emissions factor listed, the total emissions from natural gas is the product. Then, each emissions category was categorized as either precise, accurate estimate or questionable estimate and processed in various ways depending on the categorization. Precise categories were statistically analyzed using a one-sided Bayesian t-test conducted in R Studios. Accurate categories were taken as is but were not considered accurate enough or had enough responses for a proper statistical analysis. Questionable estimates had responses which were either significantly different from literature and expected results or had very low deviation between respondents. While this does not necessarily mean these estimates are different from the actual value, it means there is a higher chance they are not representative. These were still used in emissions categories as based on literature these categories had a minor effect on emissions, but they were flagged in the results and were not statistically analyzed.

In some source specific cases in which comparing net-zero to non net-zero was not comparable, the net-zero values were converted as if they were non net-zero. To elaborate, if the source is electricity, net-zero uses electricity from a renewable energy grid while non net-zero uses regular electricity, generated through a mix of renewable and non-renewable sources (in the context of Ontario). The reason for this is two-fold. First, as mentioned in Chapter 2, this is the most feasible solution to solving the issue of net-zero being incomparable to other emissions sources due to no emissions. Second, another reason to do this based on the definitions of physical and behavioural established earlier in this chapter. Under the definitions earlier, because clean energy is not widely available nor realistically achievable by anyone it would fall under BERs (Karunathilake et al., 2019). However, the emissions categories related to electricity make more sense as physical such as insulation, which is widely available (Ayylidiz & Erdogan, 2022). Therefore, along with being a good solution to the difficulties of comparing to net-zero, converting net-zero electricity reconfigures the emissions such that the reductions properly fit the previous definition of physical reductions. If the study were to use the emissions from electricity, they would be negligible/zero because the electricity from net-zero homes is all renewable. If taken as BERs this would widely skew the results. Therefore, the electricity used by the net-zero homes was converted as if they took electricity from the regular grid (i.e. the same emissions factor was applied to both) for part of the analysis. In a way, this converted them to PERs because the renewable energy is the only part of a net-zero home that is widely unachievable due to limits in renewable energy production. Finally, for participant confidentiality each emissions category was averaged and summary statistics were taken from comparisons in these averages.

3.5.3 Limitations

There were several limitations in the study, some of which were considered but unavoidable and some of which could be removed with improved design or more specific studies. The first is the available communities which fit the purpose of the study, i.e., net-zero communities. Because there is only one Ontario at the time of the study, the data pool is limited and potentially unrepresentative of net-zero communities constructed in other geographic and planning contexts. This potential to be an outlier is proven by the unique geographic context of its construction. Unlike many developments, this community was designed and built from the ground up at the edge of the city, leaving lots of room for construction. Realistically future net-zero communities might be created via retrofitting, and as such might be more limited geographically. This was an unavoidable limitation and because of this, in all aspects of analysis, the differences between this net-zero community and what might be a typical net-zero community is considered. Ultimately though, aspects which are considered atypical but beneficial to global emissions and could be applied to other communities should be considered by planners and with enough implementation could create a paradigm shift.

Second is a response bias. Due to a low population to work with, all homes in the net-zero community were given the chance to participate and all responses were analyzed. This could have resulted in more responses from households who agreed with the theme of the study, resulting in lower emissions than the true value and the overestimation of personal environmental impact. This was expected, and although it may have been possible to improve response rate with compensation would have introduced other bias, which is why this bias was deemed acceptable. This compounds with an assumed response bias that by living in a net-zero community could indicate that respondents were already predisposed to overestimate the environmental awareness and impact.

The next limitation of no control community compounded with the previous limitation to made it harder to see if there was a response bias and could be used to support the notion that those less interested in the reducing emissions would have responded less. This also means that some estimates might not be as reflective of a true control as data had to be taken from a provincial or even national scale if not available at the local scale. This was not an anticipated weakness as the study was designed with a control community but had too few responses to be usable. Future studies could rectify this by using multiple control communities or a specific study on behavioural reductions which could then be compared to these results.

Finally, the results could not test for the statistical significance of all emission sources. This was due to the design of the study. The study was designed to try and get a sense of all aspects of a household's emissions. To accommodate this, and considering the low population, the study was designed to increase response rate by letting respondents estimate, use different units of measurement, and skip questions if they deemed necessary. These estimations were not accurate enough to test significance with, such as waste produced in which every respondent estimated waste produced, but it was likely overestimated due to respondent rounding errors and unknown waste composition. With little previous research to go off and due to the holistic scope of this study, this was deemed a necessary trade-off in study design. This could be rectified in future studies by studying specific sources or case studying specific homes.

3.6 Results

The survey to the net-zero community had 8 responses from the 53 total homes, approximately a 15% response rate. From this sample climate change attitudes were scored on a Likert scale of 5 (Table 3.1). On average, the statements rated between "Somewhat Agree" and "Strongly Agree" with very little variance and leaning towards "Strongly Agree" (Table 3.1). The one outlier was the statement "I try to inform other on ways they can reduce their carbon footprint" which was rated "Neither Agree Nor Disagree" on average (Table 3.1). Additionally, every single respondent rated "Strongly Agree" on the following four statements: "I believe climate change is a big issue", "I want to stop/slow climate change", "I am concerned about climate change as a whole" and "I am concerned about the environmental effects" (Table 3.1).

Statement	Mean	St.Dev
I believe climate change exists	4.88	0.35
I believe climate change is a big issue.	5.00	0.00
I want to stop/slow climate change.	5.00	0.00
I am concerned about climate change as a whole.	5.00	0.00
I am concerned about the environmental effects of climate change.	5.00	0.00
I am concerned about the economic effects of climate change.	4.75	0.71
I am concerned about the social effects of climate change.	4.75	0.46
I think about the effects of climate change often.	4.63	0.52
I try to reduce my contribution to climate change.	4.50	0.76
I actively try to reduce my greenhouse gas emissions.	4.13	0.64
I keep myself informed on how I can reduce my carbon footprint.	4.38	0.74
I try to inform others on ways they can reduce their carbon footprint.	3.38	0.74
I have made lifestyle changes which have reduced my carbon footprint.	4.13	0.83
I feel responsible for helping reduce climate change.	4.63	0.52
I pay attention to news and developments regarding climate change.	4.63	0.74
Total	4.58	0.47

Table 3.1 – Average Likert score (1-5) of climate change attitudes.

Unsurprisingly, households in the net-zero community used less electricity and created fewer carbon emissions when compared to the city's averages (Table 3.2). When comparing electricity usage, all sources were more efficient resulting in less electricity usage in all categories except for heating (Table 3.2). While regular homes do not have any electricity usage on heating, net-zero homes use most of their electricity on heating (Table 3.2). Despite this heating increase, net-zero communities use 20% less electricity in total (Table 3.2).

	Average (kWh/month)	Net zero (kWh/month)	Emissions Equiv.
Monthly Electricity Usage	680.00	539.74	0.61
Appliance Electricity Usage	217.60	112.42	0.45
Heat	0	401.95	-1.74
AC	380.80	7.96	1.61
Lighting	54.40	17.41	0.16
		Total	1.09

Table 3.2 – Electricity usage of the average and net-zero home in London, ON and emissions equivalent of reductions from net-zero homes. Emissions equivalent is in tonnes CO_2e/year.

Meanwhile, when comparing emissions profiles, net-zero communities have significantly less at 74% fewer emissions than average (Table 3.3). In terms of source, this is mostly from residential sources which multiply electricity usage by an emissions factor of zero, resulting in no emissions produced (Table 3.3). The CO_2e of this electricity usage if the net-zero home received electricity from the regular London power grid can be found in the Emissions Equiv. column of Table 3.2. There are also more than 50% fewer emissions from transportation and approximately 30% less emissions from waste (Table 3.3). Of this 74% emissions reduction, about 60% were from physical sources, while 40% were from behavioural sources (Table 3.3).

	Average (tCO2e/household/year)	Net Zero (tCO2e/household/year)
Total Emissions	9.30	2.41
Transportation	4.30	1.93
Residential	4.25	0.00
Waste	0.70	0.48
	Physical Reductions:	-4.14
	Behavioural Reductions:	-2.75

Table 3.3 – Yearly emissions for average and net-zero homes in London, ON split by emission source and total reductions from average to net-zero homes split by reduction type.

Comparing the individual sources of the emissions reductions, the most significant was using less motorized transport, which accounts for 34% of total reductions (Table 3.4). Next were four physical improvements that were related to electricity usage: clean energy, heating via electricity, insulation and better appliances, which altogether more than half of total household reductions (Table 3.4). The last three sources each account for less than 10% of total reductions and are less waste, less electricity usage and non-propane appliances (Table 3.4). Speaking to reduction sources surveyed but not mentioned, there were no significant differences in the environmental impact of the vehicle choice. For vehicle choice this was because the vehicle choices were not different in the net-zero community.

When calculating reduction sources, results were normalized to account for inconsistencies between standard and net-zero communities (Table 3.4). This mostly pertains to sources of heating and cooling (Table 3.4). First, while emission reductions from "Heating via Electricity versus instead of Natural Gas" would be greater if used alone, it becomes lower in conjunction with "Better Insulation" (Table 3.4). Therefore, to prevent double counting, emissions reductions were applied from insulation first, as logically it would have an effect on heating via electricity, not the other way around. Additionally, the net-zero community uses electricity from a separate and completely renewable power grid, which would convert any BERs from reduced electricity usage into PERs (Table 3.4). As such, the equivalent reductions if the net-zero homes were on the standard power grid were calculated and applied to the results (Fig 3.2).

Source of Emissions Reduction	Amount	Physical or Behavioural
Less Car Travel	-2.37	B
Clean energy	-1.72	P
Heating Via Electricity	-1.26	P
Better Insulation	-0.61	P
Better Appliances	-0.45	P
Less Waste	-0.22	B
Less Electricity Usage	-0.16	B
Non propane appliances	-0.10	P
Total	-6.89	

Table 3.4 – Emissions sources, the reductions from average to net-zero home and the physical or behavioural categorization of each source. Amount is in tonnes of CO_2e/household/year.

Based on the one-sided Bayesian t-test, with 95% certainty, there is an 79.6% chance that the true mean of electricity usage in London's West5 community is less than that of the city of London. Meanwhile, under the same confidence interval there is a

92.9 % chance that the true mean of carbon emissions from transportation is lower than that of the rest of the city. When plotted, both these results show a similar left skew, with most results falling near the mean, but a few outliers that fall which were even greater than the city's average. This is represented by the large standard deviations in relation to the means of the surveyed results.

Statistical Significance	mean	sd	conf int	less %
Transportation (tCO2e/household/year)	1.8	3.4	0.95	0.796
Electricity Usage (kW/household/year)	526	427	0.95	0.929

Table 3.5 – Statistical significance of non-estimate survey results with numerical value.

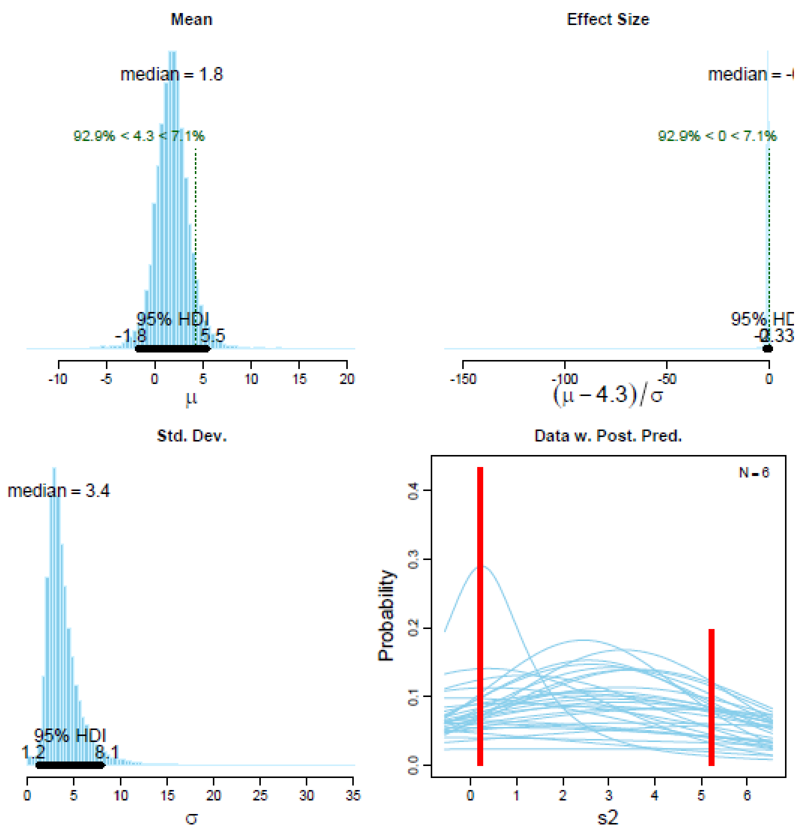

Figure 3.1 – One-sided Bayesian t-test graphs of emissions from transportation sources. Generated in R.

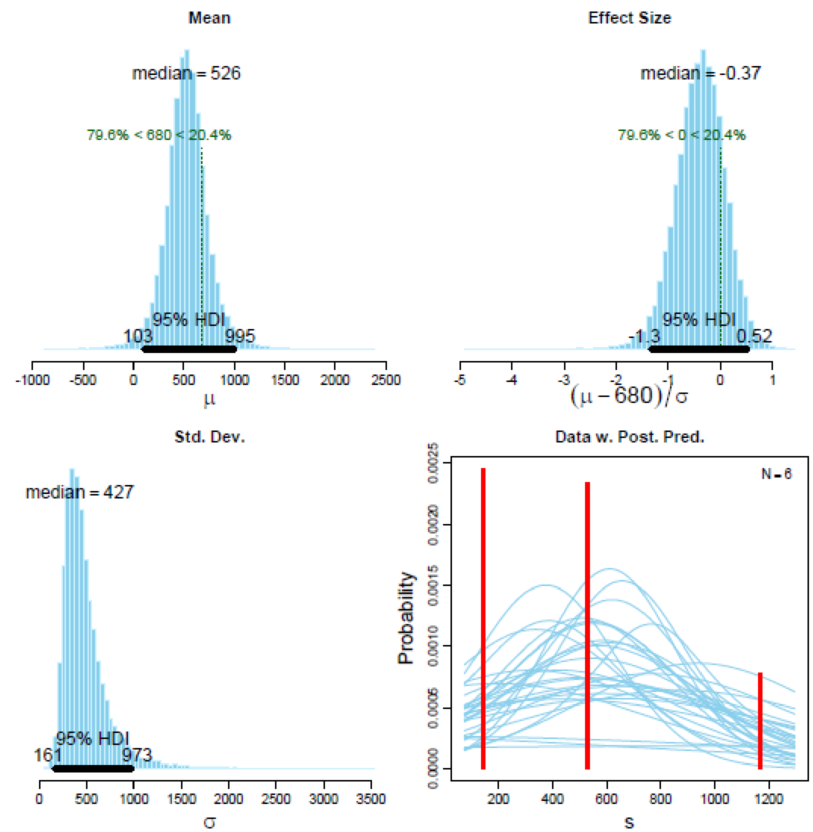

Figure 3.2 – One-sided Bayesian t-test graphs of emissions from electricity using sources. Generated in R.

3.7 Discussion

The results show, statistically speaking and with high confidence, that there is a significant reduction in both electricity usage and greenhouse gas emissions between net-zero communities and local averages. These reductions are from a variety of both physical and behavioural sources. This shows that there are many different emission sources that a net-zero community addresses to reduce emissions. Additionally, by conducting statistical analyses over greenhouse gas emissions and electricity usage and knowing the main sources of each type of emission, it can be surmised that behavioural reductions have a relatively prominent, albeit lesser impact on total emissions when compared to PERs. How both physical and behavioural sources are affected, the effect they have and how this can guide future research and policy will be further explored in this section.

To highlight some of these explorations, the BERs with the greatest potential, reducing motorized transportation, is very related to urban form, which planners have a high degree of control over. As such planners can utilize urban form to affect behaviour and greatly reduce emissions. That said, PERs were still greater so planners should still use and perhaps even prioritize PERs with methods such as zoning for developments with better infrastructure. However, the literature highlights the need for both physical and behavioural emissions reductions, so neither can be excluded.

Before anything, it is important to note that throughout the analysis it became increasingly clear that the line between physical and behavioural emissions reductions is thin and they are inherently linked, especially when considering the application of them. PERs ultimately rely on a choice to convert to them, and BERs can be reduced by or even shift into physical reductions. This is also true when considering an applicative lens as physical changes, such as more lanes on a major road, can induce a change in behaviour while behaviour changes can spur technological improvements. This is reflected in literature, many research papers that differentiate the two come to the conclusion that the two types of emissions are linked and hard to separate (Chapman, 2007; Dietz et al., 2009; Streimikiene & Volochovic, 2011). This may be why literature which separates and analyses the two and differences between the two is historically sparce (Chapman, 2007; Dietz et al., 2009; Streimikiene & Volochovic, 2011).3.7.1 Physical Emissions Reductions

The first source of PERs that must be discussed is insulation. While it was not the greatest source of emissions reductions, as mentioned, it is the physical reductions that must be applied first. Because heating and cooling is such a vital and energy intensive part of a household's emissions, insulation has a significant impact on emissions but when compared to converting heating sources is much less effective, even when applied first. Despite this, it is the least geographically impacted factor. That is because no matter the climate or heating source, better insulation is both viable and effective, however does perform better in certain climates (Ayylidiz & Erdogan, 2022)

A significant source of emissions reductions is converting heating systems in the house from natural gas to electricity. This is because the emissions factor of electricity is significantly lower than that of natural gas according to secondary data, namely the National Inventory Report (ECCC, 2021). This effect is amplified by geographic context because a large source of power generation in Ontario are from emission free sources like hydro, lowering the emissions factor even further (ECCC, 2021, Statscan). After accounting for logical consistency (i.e., insulation reductions applied first), thirty percent of the PERs are because the building envelope is heated via electricity. The geographic context amplifies the need for heating and cooling, and in a tropic country that requires less heating this might not be the greatest source of emissions reductions. In the same vein, this would be by far the greatest reduction in frigid geography, although such climates lack clean energy sources making the application of this difficult. Although these methods of emissions reductions are due to improved infrastructure, and as such is classified as a physical reduction, to enable widespread proliferation in similar geographic contexts, and beyond net-zero homes, would require the enactment of policy (Morrow et al., 2010). Otherwise, the only ways to achieve these reductions are to rely on homeowners to choose to retrofit their heating systems and encouraging this via rebates and incentives.

The next source of emissions reductions to be applied are more energy efficient appliances, although this could be applied at the same time or before the previous two as it affected by no other sources but affects one source. This is still relatively significant, however less so likely because although appliances generally have high electricity usage per appliance use, most are not run at all times, or even often when considering a temporal scale of a year.

The second last source of emissions reductions of a physical nature is propane usage. In this context, it is mostly used in appliances rather than heating, as that is done via natural gas. This means that this was a minor reduction, even though the net-zero community used standardized high efficiency appliances, because appliances are used relatively infrequently (Fujimoto et al., 2017; Sifton Corporation, 2019). As mentioned, in a place where propane is used to heat the home instead of natural gas, the reductions would be the greatest source although in this case might be categorized as heating rather than propane. This is not considering the efficiency and emissions factor of each fuel, only that said fuel is the greatest individual emissions source in the house if it is being used to heat it.

The final reduction applied is clean energy. This reduction is applied last because it is affected by all the previous categories either directly, such as heating via electricity, or indirectly, as is the case with insulation. Even with those two factors, it is still the most significant physical reduction and is the highest single reduction techniques if no other methods are taken.

These results show support for the methods of net-zero literature and show that it is very effective at reducing household emissions. PERs alone can reduce household emissions by 44% before clean energy and reduce it even further if net-zero can be fully implemented. This is before considering potential behavioural improvements from net-zero communities, which will be discussed in the next section.

3.7.2 Behavioural Emissions Reductions

When looking at the sources of behavioural reductions, household reductions (i.e., less electricity usage and waste) are almost insignificant, especially when compared to the major behavioural reduction of reduced vehicle emissions. There were no significant differences in the make and model of vehicles chosen by residents in the net-zero community, despite households being fitted with electric vehicle charging stations for faster charging (Sifton Corporation, 2019). All respondents used regular light range gas vehicles such as cars, SUVs and pick-up trucks. It is worth noting that while collecting surveys door-to-door, some electric vehicles were sighted, but not common, and might indicate the response bias was less prominent then expected. The main source of behavioural emissions reductions was the choice to use vehicles less, resulting in significant reductions.

This might give the impression that there is very little behavioural benefit to net-zero communities, as this choice might not be correlated with net-zero communities. In this specific case, the community was specifically designed as a mixed-used net-zero community (Sifton Corporation, 2019). That is to say, the community is designed to incorporate commercial buildings to meet the needs of the residential buildings so that residents do not have to travel as far for essentials and amenities. Logically, this means most of the travel done by residents was for work and recreation that is done irregularly and geographically locked, such as visiting a movie theatre. While COVID-19 might have reduced the travel reported by respondents, the emissions reported by the city of London were from 2020 and noted to be impacted by COVID as well. This implies that planning solutions to address behaviour, while not as significant as improved design, are an important aspect of improving city-wide emissions and while not unique to net-zero communities, are something designers of net-zero communities consider. Another way to phrase this is that planners should utilize physical solutions to change behaviour. This reinforces the idea that physical and behaviour are inherently linked.

Going back to the household reductions, they were not low because residents were not making the associated choices which would reduce them, but rather because household reductions had less magnitude than household improvements. In the case of electricity usage, with better technology in the form of smart homes, choosing a proper temperature, turning off lights, etc. is becoming less of a choice and more standard, almost bridging into PERs territory, which again reinforces the link between physical and behaviour. In terms of waste, the carbon emissions come mostly from transportation, and other environmental impacts cannot be calculated in carbon emission equivalents.

Furthermore, there was seemingly a small link between living in a net-zero community and their levels of awareness, climate change concern and emissions reductions. The households in the net-zero community were both very concerned and very aware of climate change and showed less waste produced and less electricity used (after accounting for electricity reductions from other sources). However, because of uncertainty in the accuracy of the household emissions, no statistical analysis could be conducted. Therefore, if the links between climate change awareness and emissions reductions want to be properly explored, further studies would be needed, specifically ones containing multivariate analysis to determine what factors between demographics, location, infrastructure, upbringing, etc. have the most and least impact.

Speaking more to the residents' attitudes towards climate change, in the statements of climate change concern, the lowest scoring statements were "I try to inform others on ways they can reduce their carbon footprint." (3.38 out of 5), "I have made lifestyle changes which have reduced my carbon footprint." (4.18 out of 5), and "I actively try to reduce my carbon emissions." (4.18 out of 5). While still strong average scores, this could indicate a possible disconnect from climate change concern and emissions reductions. It is possible that because residents live in a net-zero community, they do not feel the need to make a conscious effort, which is consistent with behaviour research in non-environmental fields (Olds et al., 2017; Verger et al., 2009). The lowest score of keeping others informed was so much lower and could have a few potential explanations, each having its own impact on a study scaled down for net-zero homes. On one hand, because they live in a well-informed community, they do not feel the need to inform them more, which in a scaled down study would show this statement to have a higher result. On the other hand, it might be that community plays a small part in environmental awareness, in which a scaled down study would not show a significant difference in this statement. It is also possible that it is neither or a combination of both of these possibilities. Regardless, this provides a lot of potential for further research related to climate change attitudes, how they can relate to community values and how they interact with other factors. Although this type of research might not have the greatest quantitative impact on emissions based on the results, it could provide the building blocks to maximizing BERs by focusing policy and improving the adaptability of these methods.

The total BERs together equated to 29.6% of household reductions, which was more than 20% reduction in household emissions which was estimated in research (Dietz et al., 2009). The reasoning for this is obvious at first, however this reason brings addition questions. The estimated 20% reduction due to behaviour categorizes all changes as behavioural, including but not limited to improved appliances, low-emission vehicles and improved insulation, all of which were categorized as PERs in this study (Dietz et al., 2009). The reason for this is this study estimated total reductions over a 10-year implementation period, focusing on realistically achievable changes without affecting people's lifestyles (Dietz et al., 2009). This focus on not disrupting lifestyles, the development of green technology and the different geographic context, with Ontario having a higher potential for clean energy, resulted in the overall reductions being lower than the reductions seen in this study (Dietz et al., 2009).

Ultimately, while the results show that behavioural reductions have merit and are effective, no link was observed between net-zero communities and improved behaviour. The behaviour links observed, which were related to transportation, were specific to this study site rather and were not inherently net-zero. Other behaviours either showed no noticeable difference or could not be observed due to study limitations.

3.7.3 Application of Net-zero Infrastructure

Taking under consideration the relatively lower impact of household behavioural reductions, further study might not be as effective as more net-zero communities or solutions aimed at proliferating the emissions reductions from net-zero communities. And, because of the potential link between net-zero living, awareness and emissions reductions this might still impact behavioural reductions. As such, the methodology and feasibility of applying net-zero infrastructure across a wider geographic range should be considered and studied further.

The first aspect of applying net-zero infrastructure is ease of implementation. Retrofitting a home to use an electric furnace rather than natural gas is a relatively simple. Meanwhile, to reduce average distance travelled is both more complicated and time consuming. Rezoning is needed to enable mixed-use communities, time is needed for construction of suitable commercial spaces, businesses need to become interested and set-up, etc. Despite this, because it is the most significant form of emissions reductions are a net-zero community, it would be preferable to take steps towards this sooner rather than later. Further studies could be used to evaluate if the time and money invested to reduce travel time is worth it compared to the time and money that would be used to implement proliferation policy.

Next, is considering the scalability of these reductions. The physical reductions from net-zero homes scale at an exponential as you go from a low scale, such as net-zero homes, towards a medium scale, the net-zero community. This is because energy generation is more efficient at larger scales. Despite this, at a theoretical net-zero city scale, the scaling might be more linear due to transport loss of electricity that would be more prominent at the city scale.

Meanwhile, the effects of behavioural reductions at larger and smaller scales remains unclear as they are unexplored in literature. The aforementioned behavioural effects of transportation generally would not be a factor when scaling up to net-zero city as most cities were not intentionally designed to reduce travel. Altering a city to fit this design would take a lot of time and policy changes. Additionally, on the city-scale, you also have to consider transportation from heavy transport vehicles such as buses and trucks. When scaling down, you would likely see more emissions and a higher standard deviation, as most homes are not designed to require less transportation, but some are. It is important to note that over the next few years, with electric and hybrid vehicles potentially becoming more prolific, that emission from this source may naturally decrease. This would reduce the potential emissions reductions from using motorized transportation less, similar to how insulation lowers the amount converting to electricity heating can reduce emissions. Should electric become the new normal for motorized vehicles, that also might change vehicle make and model to be an interventions better categorized as PERs rather than BERs.

Considering the scaling of other BERs, it is unclear if the behavioural reductions to waste and electricity usage would be relevant or significant if applied to the same amount of separate, singular net-zero homes. While the standard deviation was a large ratio in comparison to the mean, this is exacerbated by the low sample size. Therefore, while it is possible that having a dedicated community could positively influence behaviour, further research is needed to investigate these effects, if any. At a larger scale it is also unclear to what effects behaviour may have. In this case, while further research is also needed, it may not be possible except in a theoretical context or by scaling up smaller scale net-zero research like what is done for net-zero city research (Seto et al., 2021).

3.7.4 Application and Future of Behavioural Reductions

Although behavioural reductions are lower impact than physical, they still have merit to them. First, physical reductions are relatively static, while behavioural have more variability. While this can result in fewer emissions reductions, this also means there is potential for increased reductions especially if other physical methods are not being applied first for logical consistency. Second, behavioural reductions are more widely applicable. While there are barriers and feasibility issues to implementing net-zero and other physical reductions, behavioural reductions have few to no obstacles (Girod et al., 2014; Reames, 2016; Streimikiene & Volochovic, 2011). Finally, these approaches for emissions reductions are not mutually exclusive, and to reach the emissions targets laid out by the federal government, both physical and behavioural emissions reductions will be needed. Therefore, it is also important to consider the potential application and scalability of behavioural emissions reductions on their own.

3.8 Conclusion

Overall, net-zero communities have a large effect on household emissions, greatly reducing average emissions. The study also shows that behaviour can have a significant effect on household emissions, even in a context where physical changes were the goal. Speaking to the application, and as such speak to how these results can be used in a planning context, while changing behaviour can have a similar effect in reducing emissions, improved infrastructure can do so at larger volumes more easily and realistically. That does not negate all the benefits of behavioural emissions reductions. While the results show less of an impact from behaviour on emissions, they can be at least 50% as effective as technological improvements and depending on implementation costs could be a more cost-efficient method of improving emissions short-term. Additionally, because many behavioural emissions reductions are not inherent to net-zero communities, physical or behavioural reductions can be chosen on a community-by-community basis based on what the local context demands. Long-term, it is necessary to implement all possible methods of emissions reductions to sufficiently lower global emissions.

Furthermore, this study only begins to touch upon the many aspects of behaviour and emissions because there are many aspects of behaviour that are still not fully understood, especially in the context of planning and climate change. This leaves potential for both further research and for application. In terms of further research, this includes a further breadth of research and a further depth. The breadth of this type of research can be expanded by looking at more than just household emissions and expanding to behaviour in the workplace or behaviour of different bodies of people (ex. corporations, religious bodies, ages). Meanwhile, depth can be added by improving the methodology, such as improved response rate and additional study communities or adding a more multivariable approach. To elaborate, seeing how different variables interact and improve or worsen emissions in conjunction with another could improve policies as they are able to account for their local context. Depth could also be added by further defining or even redefining physical and behavioural emissions reductions in ways which are not limited by study design and instead focused on the most realistic, accurate and applicable definitions. It is likely that depth would be the more optimal from a logical and academic point of view, as it is best to perfect the methodology in one area before moving to the next, however from an application and realism point of view, breadth would be more optimal as it can target other emissions sources.

Chapter 4 – Does Better Behaviour Propagate Additional Climate Action?

4.1 Abstract

Using the same dataset from "Chapter 3 – Better Technology Versus Better Behaviour: What Are the Benefits of Net-Zero" another analysis was conducted to understand commonalities between behaviour sets which improve climate change impact, referred to as behaviour clusters, based on behaviour clusters researched in health research. After conducting an analysis on the 8 of 53 households surveys in Ontario's first net-zero community, behaviours related to food waste had a strong relationship with many other emission reducing behaviours, while electricity usage was more independent from other behaviours. In general, respondents favoured greatly improving their behaviour in a small number of climate related actions rather than improving all climate behaviours a small-medium amount. While no specific behaviour clusters were identified, the analysis provided evidence that behaviour clusters of some sort exist. Future studies related to behaviour clusters should focus on a large sample size and increasing response rate to address weaknesses in existing behaviour cluster research. By focusing on quantity over accuracy to reduce sample bias, this will provide a foundational understanding to what behaviour clusters can exist in a given population and how they relate to behaviour clusters in other fields.

4.2 Introduction

With such a wide range of emissions statistics being surveyed, the dataset from "Chapter 3 – Better Technology Versus Better Behaviour: What Are the Benefits of Net-Zero" is adaptable and can be rescoped to be applied to other analyses. One potential analysis that can be done with this data is to analyze how different choices and behaviours relate to each other. Behaviour is not an independent variable, it is affected by many things both known and unknown including but not limited to demographics, upbringing and economic status (Wynes et al., 2018). Not only do many factors affect behaviour, so too can one factor affect many behaviours (Reames, 2016). For example, being in a poor economic standing could potentially mean your behaviour will skew towards saving money, and this will take effect in multiple choices, not just one (Reames, 2016). Extending this example, even factors seemingly unrelated to environmental sustainability can affect it, so money saving techniques are, generally speaking, more likely to produce fewer emissions (Wynes et al., 2018). In other words, one factor can affect many different behaviours to have a compounding effect on emissions behaviour (Wynes et al., 2018).

Based on this idea, there may be trends in behaviour which are likely caused by similar factors or behaviours which can be targeted at once, which will be referred to as behavioural clusters. This has the potential to improve time and cost efficiency of policy-based planning solutions as planners will be able to affect many behaviours which may compound together for greater emission reductions (Wynes et al., 2018). Behaviour clusters are not a new idea to academia, however they have yet to been researched in a meaningful way in planning contexts. Instead, the literature base must be taken from other bodies of research. One prominent field of behavioural cluster research is health-related behavioural clusters. In these settings, behavioural clusters can act in ways that are contrary to the first assumption (Olds et al., 2017; Verger et al., 2009; Williden et al., 2012).

In health-related fields, this behaviour cluster research is more focused on negative health behaviours rather than positive ones (Guo et al., 2020; Twisk & Senserrick, 2021; Verger et al., 2009). While these behaviour clusters were not always predictable, negative behaviours clusters seem to cluster more than positive behaviour clusters (Guo et al., 2020; Twisk & Senserrick, 2021; Verger et al., 2009) The question remains in whether or not environmental behaviours cluster in similar ways. If they do, planning research can borrow from these principles for more applicative purposes.

4.3 Behaviour as a Cluster, rather than as Units

It is important to define what a behavioural cluster for clarity as it is not a well-defined term in literature, or at least in climate change and planning literature, with the definition being implied from the compounding of words (Olds et al., 2017; Verger et al., 2009). While in its simplest form, a behavioural cluster is simply the common patterns in people's actions, it is also important to consider that this must be applicable to a wider scope to support the applicative/planning nature of this study (Verger et al., 2009). Behavioural clusters can also be more focused, as it is in this case, and can be in the context of certain fields, for this study that field being carbon emissions. To amalgamate all parts of this definition, in the context of this study, a behavioural cluster is a common combination of behaviours which have an effect on carbon emissions such that planning policy can target a cluster of behaviours rather than try and make individual policies for individual behaviours.

The reason behaviour should be considered as a cluster rather than as a unit, as implied by the application portion of the definition, is that it is more efficient and effective to target multiple behaviours with a single policy (Mai & Hoffman, 2012). The issue is that behaviour can sometime be contradictory to first impressions, making it hard to understand behaviour clusters without research (Olds et al., 2017). That is not to say that these behaviours cannot be explained, but rather that the explanations are not always the most expected explanation, the explanation which a researcher might base their hypothesis around (Olds et al., 2017). Essentially, behaviour as a unit of study is variable and volatile, therefore while it is optimal to design policy around behaviour clusters, it is much more difficult to identify usable behaviour clusters relative to individual behaviours.

The key to identifying an applicable behaviour cluster is reducing variables in the already variable heavy analysis (Williden et al., 2012). This was done by limiting the scope of a study, in this case the geographic scope. The purpose of this was to reduce lurking and confounding variables and in turn increase the confidence of the behaviour cluster existing, with the downside being increased potential for bias and less wide-range applicability.

As noted, the application of understanding behaviour clusters is a matter of efficiency (Verger et al., 2009). If targeting one behaviour can cause an improvement in many behaviours, then planning policy can be specific in purpose while still having a large effect on greenhouse gas emissions. It can also improve the adaptability of planning at local contexts. Literature shows that understanding local context is key to implementing green infrastructure, and logically is key to implementing any planning initiatives (Jones & Kammen, 2011; Schifman et al., 2017). Understanding local behaviour clusters can give deep insight on many aspects of the planning process, including what residents want, what they need and how a given policy or change might affect these wants and needs.

4.4 Methods

4.4.1 Data collection and analysis

The data for this study was collected from the first net-zero community in Ontario located in London and a similar control community in the same city (Williams, 2018). The data was collected via mail back surveys, door-to-door surveys and online surveys, with participants able to choose the method which suited them the best. These surveys can be found in “Appendix 3: Complete Survey" and were designed to collect a broad set of emissions data by asking for estimates on emissions data which could be considered cumbersome to report or report accurately. The cost of this was that some responses were less accurate. From these surveys, responses were converted to annual CO_2e emissions using emissions factors taken from or derived from other research and sources, such as the National Inventory Report. Due to insufficient control responses, this data was then augmented with secondary data, primarily from governmental sources at all jurisdiction levels (i.e. municipal, provincial and federal), with municipal data being prioritized for accuracy.

For each respondent, each emission was rated as above, below or near the control average. In cases where there was no control average the individual responses were compared to another reasonable statistic, such as median response or community average. These cases are noted in the results section. Near the control average was defined as within 5% of the average in either direction. The relationship between each response was then compared and averaged across all response pairs. If a pair of responses had the same value (i.e. above, below or near average) then the relationship between those categories would be 1. If the pair of responses had one response that was above average while the other was below average the relationship would be 0. Relationships were categorized as 0.5 in all other cases. These relationship pairs from each respondent were averaged with the same pairs from each other respondent into a relationship matrix which denoted the general relationship between each category of responses. This relationship score is not a formal statistical analysis and is a simple indication of how these relationships interact with one another. Because of the method of calculation, there is a finite number of possible relationship scores, exactly 15 scores ranging from and including 0 to 1.

4.4.2 Limitations

The limitations for this study were all related to the fact that these surveys were designed and purposed with other primary objectives in mind, and therefore is not perfectly suited to analyses related to behaviour clusters. While adaptations were made to the emissions categories to accommodate the data set, some of the data could be more bias in a certain direction or misleading. This bias is amplified by the fact that this was a specifically purposed, closed community. That means this data might be unrepresentative of other communities in Ontario and should be considered in the results but does not nullify findings. This is also amplified by a response bias as the data was done on a small specific community, which necessitated the entire community being surveyed to maximizer response rate. Finally, these relationship scores were based on categories which generalizes the results in a way that could also be considered misleading. This also meant a formal correlation calculation could not be applied and only general relationship scores could be provided.

4.5 Results

Of the 7 respondents, 5 respondents reported overall fewer emissions than elsewhere in the country, indicated by the total rating of above 0.6 (Table 4.1). Meanwhile two respondents were about average, indicated by a total rating of between 0.4 and 0.6 (Table 4.1). Despite being above average overall, the highest rating was not above 0.75, which is relatively not high (Table 4.1). The higher rated respondents are attributed more in part to fewer factors with greater emissions rather than more factors with less emissions (Table 4.1). In other words, they were rated well because they avoided poor emissions behaviour rather than consistent good behaviour. On average, the respondents had emission reducing behaviour in less than half of the reported categories (Table 4.1). The factors with the most reducing behaviour were climate change concern, electricity usage and motorized transportation distance (Table 4.1). On the other hand, the factors with the most emission increasing behaviour is waste awareness (Table 4.1).

	1	2	3	4	5	6	7
Climate Change Concern* (above 4/5)	-	-	-	-	-	-	-
Electricity Usage	-	+	-	-	-	-	+
Appliance Usage	+	-	=	=	-	=	+
Heating/Cooling	=	-	+	-	=	-	=
Waste Awareness	+	+	-	-	=	+	-
Waste Created* (median: 90L)	=	=	=	=	=	-	=
Waste Diversion* (median: 65L)	=	=	=	=	+	+	=
Local Food* (avg: 54%)	+	=	-	=	+	=	-
Food Waste	=	-	=	=	+	-	-
Motorized Transportation Distance	-	-	-	-	-	-	-
Total Rating:	0.5	0.65	0.7	0.75	0.55	0.7	0.65
Fewer Emissions	3	5	5	5	4	6	5
Average Emissions	4	3	4	6	3	2	3
Greater Emissions	3	2	1	0	3	2	2

Table 4.1 – Survey responses compared to notable benchmarks and overall environmental awareness rating (0-1). Benchmark is national average except when noted with an asterisk, in which benchmark is noted. (-) represents under 5% of benchmark, (+) represents over 5% of the benchmark and (=) represents within 10% of average. Respondents numbered and actual numbers omitted for respondent confidentiality.

Of the relationships, 10 out of the 45 relationships were strongly related, 9 were unrelated or inversely related, and the remaining 26 relationships were weakly related (Table 4.2). The factor with the strongest relationships was food waste with 4 strong relationships (Table 4.2). The factor with the most inverse or lack of relationships was electricity usage (Table 4.2). Most of these factors have a relationship score of either 0.500, which there are 10, or 0.571, which there are 9 of, in total comprising of about ~40% of possible relationships (Table 4.2).

	Climat	Electri	Applia	Heatir	Waste	Waste	Waste	Local I	Food \	Motor
Climate Change Concern*	1.000	0.429	0.643	0.500	0.500	0.571	0.357	0.500	0.500	0.571
Electricity Usage	0.714	1.000	0.500	0.500	0.500	0.571	0.357	0.357	0.357	0.714
Appliance Usage	0.500	0.500	1.000	0.571	0.429	0.643	0.571	0.571	0.571	0.500
Heating/Cooling	0.643	0.500	0.571	1.000	0.429	0.786	0.571	0.429	0.714	0.643
Waste Awareness	0.500	0.500	0.429	0.429	1.000	0.500	0.571	0.714	0.429	0.500
Waste Created*	0.571	0.571	0.643	0.786	0.500	1.000	0.786	0.643	0.786	0.571
Waste Diversion*	0.357	0.357	0.571	0.571	0.571	0.786	1.000	0.714	0.714	0.357
Local Food*	0.500	0.357	0.571	0.429	0.714	0.643	0.714	1.000	0.714	0.500
Food Waste	0.643	0.357	0.571	0.714	0.429	0.786	0.714	0.714	1.000	0.643
Motorized Transportation Distance	1.000	0.714	0.500	0.643	0.500	0.571	0.357	0.500	0.643	1.000

Table 4.2 – Relationship matrix of different categories of survey responses.

4.6 Discussion

The results of this analysis provided many insights on the nature of behaviour clusters in the context of carbon emissions, a relationship that is altogether unexplored in both planning and general climate change research. The main takeaway of this analysis is there is evidence for emission related behavioural clusters. While specific clusters were not identified, if future research identifies these behavioural clusters than a planner can utilize methods to affect one of those behaviours to improve many behaviours. For example, if a behavioural cluster between less motorized transportation, increased recycling and amount of local food purchased, planners could affect two emissions sources they could not normally affect by altering urban form to reduce transportation. This is contingent on future research which further explores behavioural clusters in the fields of environment and planning.

However, because of the low sample size, these results are not appropriate for planning application. While this was originally thought to be a potential strength of the analysis because it reduced lurking and confounding variables, the sample size was too small to make up for the introduced biases and because the geographic context could be too niche to apply results at even a local scale (Lindon, 2014; Williden et al., 2012). To elaborate, being the only net-zero community in Ontario means that there are behaviour affecting factors which shift behaviours that might not be applicable in any other context except future net-zero communities.

This does not mean any behaviour clusters found are completely unapplicable, but it would be unwise to apply them without first researching how they would transfer to more typical geographic contexts. To be more specific, some of the emissions categories, specifically those which could not be normalized (i.e. climate change concern and motorized transportation distance) have generally lower emissions generated than provincial/national averages (City of London, 2020; ECCC, 2021). Even electricity usage, which could be normalized, show below average emissions generated (City of London, 2020). These three categories and the relationships between them are more a function of net-zero communities rather than a function of behaviour and potential behaviour clusters. In terms of biases, issues with the survey and self reporting still remained. This applies to waste created and waste diverted, where these two had the majority of respondents round their estimation to the same value, despite the survey asking for unrounded values. This means that most of these values are both inaccurate and overestimations of the true value. Second, some of the values were compared to averages within the community due to lack of necessary secondary data. This applies to climate change concern, waste awareness and local food. This technically also applies to waste created and waste diverted due to respondents reporting in volume rather than weight, but the main issue is the previously mentioned reporting issue as if the number were more accurate a weight could be estimated and examined. For these three categories (climate change concern, waste awareness and local food), an arbitrary number had to be selected which represented more, less or equal emissions. For climate change concern and waste awareness, this was below 75%, above 80% and between 75% and 80% respectively. These are likely fair estimations and did not bias the results too much because these are more objective factors, especially in the case of waste awareness. Although climate change awareness is less objective, it was measured through 15 questions averaged out which helps make it more objective and accurate than a single question rating climate change concern.

Meanwhile, local food is an interesting case. Rather than an arbitrary number, respondents were weighed on an average of all respondents. The issue with this was that the high average of 54% felt higher than a provincial/national average, however this feeling could not be backed up by any secondary data. If this average was higher than the true average, then the local food section would look similar to the electricity usage, however this would be due to behaviour rather than the nature of net-zero. To summarize, if the percentage of local food that the average Ontarian/Canadian purchases is under 54% of all food they purchase, then net zero communities may cause better behaviour in this manner. It is also possible that this factor could also be impacted by misreporting, however the variety and specificity of the reported percentages make this less probable. It is also possible that a lurking variable which is specific to this community is causing this number to be higher than average, assuming the national average is lower.

4.6.1 Potential Behaviour Clusters

With that covered, the individual behaviours and potential behaviour cases can be analysed. Overall, there were not many patterns throughout. This is consistent with the nature of behaviour clusters in literature in that the clusters were not always consistent (Olds et al., 2017; Verger et al., 2009). First, the factor which was the most indicative of overall rating was waste awareness. The most important reason for this is because waste awareness was the most objective factor asked about. All other factors were influenced, albeit minorly in some cases, by external factors such as household size. Meanwhile waste awareness, could only ever be correct or incorrect. The most objective factor also being the most indicative of generally rating also has other implications. Essentially, if another factor(s) that was not completely objective was the most indicative, that might imply that a certain behaviour that links those factor(s) creates the most prominent behaviour cluster. Meanwhile, an objective factor indicates either there are no significant behaviour clusters or all behaviour clusters essentially cancel each other out.

Speaking of behaviour clusters, there seems to be one prominent one. This is waste-related behaviour between waste created, waste diverted, local food and food waste. In the case of these factors, reducing emission in one usually indicates a respondent is reducing emissions in all those. As a whole this behaviour cluster and behaviour clusters in a theoretical sense work because one decision or subset of decisions, in this case decisions pertaining to waste and food, are all affected by similar factors, both physical and non-physical (Williden et al., 2012). The obvious link is between waste created and food waste, where the linking factor is how conscious one is if their waste, this including garbage, recycling and compost, which are related to the factors of waste created, waste diverted and food waste collectively. The decision for choosing to buy local and creating less waste are less obviously connected, but local food has less packaging than food that has to be shipped and preserved, reducing waste (Nikravech et al., 2020). It is important to remember that local food is a percentage of total food in this study. Therefore, it is possible that some of the local food percentages were higher because less food was purchased due to relatively smaller households. Less food purchased both increases percent local food and decreases food waste.

Despite the results and logic supporting this cluster, based on weaknesses in the survey and low deviation in responses for waste created and diverted, it is possible that the behaviour cluster is between only waste diverted, local food and food waste. This is based on the two non-rounded responses and logic that waste created and diverted might be inversely related. The logical side to this is, recycling more generally means you will throw away less garbage and throwing away waste that could be recycled will increase waste created. Additionally, there are no significant logical connections between local food and waste diverted, making waste diverted even less related to the rest of the cluster. However, while behavioural clusters sometimes follow logical connections in literature, in other cases this is not true (Olds et al., 2017; Verger et al., 2009). Therefore, while there is reasonable doubt on this cluster, there is more proof for this cluster than against it.

Speaking more to potential behaviour clusters, while no other behaviour clusters were observed, there is a chance that additional behaviour clusters exist. This is because individual respondents rated similarly in their emissions profile, with a similar number of factors contributing to their high rating. Despite this, the factors which contributed to this rating were inconsistent past those innate to net-zero. That implies that when people try to reduce emissions, they focus on improving a few behaviours, rather than improving all aspects of emissions. This is similar to the results in health-related behaviour clusters where those who made a health-improving lifestyle choice did not make other health-improving lifestyle choices and focused on the one (Olds et al., 2017). These two cases are also similar in that they are both related to improving behaviours rather than harmful behaviours (Olds et al., 2017). It is possible that behaviour clusters exist more prominently and are more predictable in certain environments, namely those related to negative behaviours, however this would need further research to confirm or refute (Verger et al., 2009). While knowledge of negative environmental behaviour may not be as applicable as positive behaviour, policy can be formed to prevent negative environmental behaviour, which would be especially effective if negative behaviour clusters are more prominent. This is an indicator that similar behaviour clusters in other fields could be applied to environmental behaviour and planning if the behaviours are similar.

Speaking more to the evidence of behaviour clusters in this context, if respondents generally improved all behaviours equally then there would be no possibility for behaviour clusters. The absence of this type of behaviour proves the possibility of behavioural clusters. This means to see more behaviour clusters, what is needed is more results as with enough respondents, any behavioural patterns between factors becomes clearer (Williden et al., 2012). This will also further the understanding of how environmental behaviour clusters relate and compare to behaviour clusters in other fields. This can reduce the need for environmental behaviour research and allow planners to utilize research from other fields. For these results of this study, most respondents seemed to be in different behavioural clusters if behaviour clusters exist in this community.

Next individual factors and relationships will be analysed. These individual relationships could be considered small behaviour clusters, however this just amounts to correlation. Of the factors, two stand out as being different in nature to the other factors, in that they are less of behaviour changes. These are climate change concern, which is more of a change in thinking and opinion, and waste awareness, which is more of a test of knowledge and memory. In the case of climate change concern, there is still some connections between changing thinking and changing behaviour as they arguably lead into one another. Knowledge on the other hand, is much more independent from behaviour. If that knowledge is directly related to said behaviour, then it may have some effect but if that knowledge is independent of said behaviour it should not have an impact. Taking waste awareness as an example, knowing what is and is not recyclable might mean you recycle more, but does not necessarily mean you set your thermostat to an energy conserving temperature. Examining the relationships seems to support this notion, with all relationships being equal or under 0.5 except for waste diversion and local food, with local food being the highest. One would expect waste diversion to be the highest but there are some factors which may be lowering it, namely that awareness was rated on an objective scale whereas waste diverted was subjective.

To elaborate, it is a simple matter to say where a given form of waste should be sorted (garbage, recycling, etc.) and this is independent from how well a respondent perceived their waste sorting ability. Meanwhile, a respondent could have reported recycling twice as much as anyone else, but missorted half of it, leaving the actual waste diverted and reported waste diverted completely different. Essentially, while waste awareness would likely be correlated to actual waste diversion, due to weaknesses in methodology, this might not be the case. In fact, looking closer at the results, the only reason the relationship between the two factors is not weak overall, like the relationship between waste awareness and waste produced, is a single respondent who demonstrated a strong relationship. Overall, this shows that collecting waste data is not a simple matter and may require very specialized studies, potentially in collaboration with waste management/collection groups to improve accuracy (Gooch et al., 2022; Streimikiene & Volochovic, 2011, Young et al., 2017).

The disconnect between waste awareness, waste created and, to an even greater extent, food waste might seem surprising at first, however after logical deduction, it can be surmised that these two factors may also independent of waste awareness. Knowing how to sort waste will not decrease total waste produced, however may sometimes help turn some of that into waste diverted. It also does not stop food from going bad any slower. Although one might argue those more aware of waste sorting would be more environmentally conscious as to not produce as much food waste, that logic could be applied to any of the emissions categories. Ultimately and as previously mentioned, waste awareness is unique in that it is more of a knowledge exercise rather than a change in behaviour which is the cause of this lower than expected relationship score (Gooch et al., 2022).

Another interesting relationship is electricity usage's many inverse or non-relationships. Electricity usage was related to waste diversion, food waste and local food in this way. If one were to consider this an inverse relationship, then there should be a reason for this. The relationship can be partially explained by the behavioural cluster those three factors fall under, however this must be accompanied by an explanation to why it is inversely or unrelated to at least one of these, otherwise the factors being in a behavioural cluster is irrelevant. When finding an explanation, it is also important to consider that these three factors had weak relationships with appliance usage and heating/cooling, so while the explanation must be related to electricity usage, it cannot be related to those aspects of electricity usage. Ultimately, no logical explanation could be surmised, leading to the conclusion that there is either no relationship or that more data and qualitative studies are needed to determine if this relationship is an inverse one and the cause of it.

4.6.2 Positive and Negative Behaviour Clusters

From evidence in health-related behaviour clusters and based on the patterns found in this limited dataset of climate-related behaviour clusters, behaviours which would be considered positive, as in health improving and emission reducing behaviours, do not cluster like negative health behaviours (Guo et al., 2020; Twisk & Senserrick, 2021; Verger et al., 2009). However, it is unclear if negative climate behaviours cluster the same as negative health behaviours because the dataset used focused solely on environmental improving behaviours. Health related literature suggests the reason positive behaviours were not clustering may be because salient physical changes were not present in participant's daily lives (Williden et al., 2012).

Another explanation is that health and potentially environmental actions are done until the user believes their actions are sufficient (Williden et al., 2012). For example, especially in health research, if the goal is to be physically healthy, a person can feel healthy enough by just improving their diet or just exercising regularly (Williden et al., 2012). Essentially, this is a matter of perception rather than a matter of concrete results, where people believe their results are sufficient regardless of whether or not they objectively are. Taking the inverse reasoning based on perception, this could be why negative behaviours cluster. To elaborate, in health behaviour clusters, specifically mental health clusters, negative behaviours compound because perception

These positive health behaviour studies also indicate the chance that they, like this study, were done on a group that was too niche to be representative of the wider population, so it could also be possible that positive behaviours do cluster and there has not been a study with a broad enough sample to properly expose them (Williden et al., 2012). There is less ambiguity for negative behaviour clusters as these studies are more plentiful and broader, making it clearer that negative behaviours generally do cluster (Guo et al., 2020; Twisk & Senserrick, 2021; Verger et al., 2009). Overall, it is likely that there are significant differences in the way positive and negative behaviours cluster however because positive behaviours are less explored and of greater concern, more research is needed.

Another commonality in the methodology of this study and most behavioural cluster studies, is that behaviours were self-reported, which could have an effect on the results in many cases. This provides a possible explanation to the inconsistent nature of behaviour clusters within studies, as self-reporting can be less accurate and is affected by an individual's perception (Williden et al., 2012). In some studies, if the self-reporting is more objective, such as reporting if an individual eats five servings or fruits and vegetables a day, or in this study's case, waste awareness, the answer is an objective yes or no, right or wrong, and therefore is less biased by self reporting (Gooch et al., 2022; Reedy et al., 2005; Williden et al., 2012). However, in other cases, such as if an individual feels as if they do enough for their health or environment, or when using estimates, the decrease in accuracy becomes more of a concern (Williden et al., 2012). Related to this, positive behaviour studies more commonly used less objective methods or were by their nature less objective (Olds et al., 2017; Williden et al., 2012)

Another key takeaway from this analysis is how behaviour clusters can be identified in future studies. The first key step is that because current research is not completely clear what influences behaviour clusters, and because behaviour clusters behave in unexpected ways, rather than hypothesis-first, studies should gather data and begin forming assumptions based on this data (Olds et al., 2017; Verger et al., 2009; Williden et al., 2012). This should also be more objective as to ensure the accuracy, remove biases and overall improve the confidence of the findings. The second key is as stated earlier trying to reduce lurking and confounding variables but this should not be done by limiting geographic scope, in turn reducing sample size.

Keeping in line with everything discussed thus far, a future study could investigate and confirm if negative environmental behaviours cluster and if they do cluster apply this by making greater efforts to prevent negative behaviours. Additionally, future studies on positive behaviour clusters with more purposed methods would be equally as valuable, or even a study which investigates both positive and negative behaviour clusters at the same time. Regardless of the focus, additional behaviour cluster research will inform future applications for environmental behaviour clusters, and allow planners to implement creative environmental solutions while borrowing from principles of other fields of behavioural research.

4.7 Conclusion

Although there was no conclusive evidence of any specific behaviour clusters, due to the patterns in the results and their existence in other fields of study, there is a good chance that they do exist. With a wider sample and more focused methodology, there will likely be multiple behaviour clusters found of varying effectiveness. The main takeaway from this analysis is that there are many dimensions and complexities to the relationships between climate change behaviour. And as highlighted in other fields of behaviour cluster research, the methods and theories behind behaviour clusters are underexplored even outside of environmental behavioural clusters. While it may not be possible to explain all of them, even with few results some patterns begin to arise. People tend to focus on certain behaviours, letting others fall to the wayside, rather than having a lesser focus on all positive behaviours.

Future research should focus on a wider demographic and higher response rate without a targeted audience like how this study targeted net-zero communities. A study like this will have more potential to discover behaviours clusters and be more comparable to behaviour clusters researched in other fields of research. While accuracy is also important, bulk would be a slightly higher priority because more responses reduce the effect of outliers, improving accuracy, and smaller more concentrated studies are more susceptible to bias, making overarching patterns hard to discern. After patterns are identified via large-scale collections, detailed qualitative studies can than be used to determine the cause of these clusters and the potential policy applications catering to these clusters could provide.

Chapter 5 –Discussion and Synthesis

5.0.1 Net-Zero Infrastructure

From the analyses regarding the topic of net-zero, emissions and behaviour there are a number of takeaways, especially when considering the two analyses in conjunction with one another. From the first analysis, which primarily related to net-zero and emissions, is that in a net-zero community,emissions are reduced primarily via physical methods are more significant than behavioural emissions reductions. PERs were found to reduce emissions 1.5 times more greenhouse gases than BERs. That being said, the impact of net-zero communities is primarily an improvement to PERs and the behavioural aspects of net-zero communities are either not intrinsic to net-zero or do not provide a significant quantitative benefit from a logical analysis. The analysis also implied that net-zero communities always increase climate change awareness but do not always improve behaviours which would cause reduced emissions. This in turn implies that the benefits of net-zero communities are surface level, as in there are not many secondary or tertiary benefits, only the benefits in which they are designed for. These primary benefits are significant even when considering the more realistic aspects of implementing net-zero at larger scales, such as insufficient renewable energy to power net-zero infrastructure at the largest scales. Altogether, this leads to the conclusion that net-zero communities are worth further investment as a method of greenhouse gas emissions reductions.

This basic conclusion does not take away or lessen the impact and importance of BERs, because as noted in literature there is a need for alternative climate change solutions, and because it is not the only conclusion that can be taken from these studies

(Boies et al., 2009; Chapman, 2007). Even though BERs were not inherent to net-zero infrastructure, they did have a noticeable effect on total emissions. Additionally, even considering that the assumptions of physical and behavioural reductions in this study were defined in a way which makes redundancy impossible, even by the most generous assumptions and definitions, the two methods will never completely overlap. Baring drastic and unrealistic change, there are some emission sources which can only be reduced through physical changes and some which can only be reduced through behavioural changes.

Upon further analysis of the redundancy of physical and behavioural reductions, it is probably that the setting detracted from the potential effects of BERs. In this context, for logical reasons, PERs were prioritized, causing BERs to suffer from diminishing returns. While the justification of this study and literature is that BERs fill gaps that technology does not, due to the similarities between the two, there is overlap especially when considering the different ways BERs can be defined (Chapman, 2007; Dietz et al., 2009; Streimikiene & Volochovic, 2011). In more typical contexts, where the technology has not been applied and therefore has very little impact, there are more emissions for behaviour to affect. The more redundancy between the two categories, the more potential behavioural methods have in more typical study settings. This could also be why there was some disconnect between awareness and BERs as expected; because the emissions behaviour usually aims to address were first being reduced physically. As such, a more accurate analysis might involve categorizing how likely any given emissions source is to be reduced by physical or BERs, which can quantitively show the redundancy between these two categories. Such a study might find that in more cases, because of lack of access or funds, behaviour is more likely to have an effect, even if physical reductions have the potential to be quantitatively larger. Essentially, this value of PERs being 1.5 times better than BERs should not be considered an estimate or even average of the relationship between physical and behavioural emissions reductions, but rather the floor, or on the low end of the spectrum. In the setting, which was most optimal for PERs, at least in a residential setting, BERs filled in the emissions gaps and were still 66% as effective as physical.

All that considered, even if an emission source can be addressed by either a physical or behavioural method, it might still be preferable to apply the physical method first as it will likely be one method that has a large effect rather than many small methods which compound into a large effect. This is because the simplest solution is often preferred. This means that the best way to interpret these results would be that physical reductions and improved technology should be applied to a given population first, while behavioural methods can be applied to the gaps which physical methods cannot address. This assumes that the two biggest issues for net-zero, cost and scalability, are not an obstacle and when they are then one must default to behavioural solutions (Shandiz et al., 2021; Young & Brans, 2017).

This conclusion highlights one of the driving issues for this study, that the focus for reducing greenhouse gas emissions is based on improving technology but focusing solely on those methods leaves gaps in potential emissions reduced (Johansson, 2009; Kromer er al., 2010; Lee & Lee, 2014; Morrow et al., 2010; Streimikiene & Volochovic, 2011; Wynes et al., 2018). Overall, this research proves that said gap is sufficiently large and even in best case scenarios (i.e. net-zero context) technology cannot address all emissions indicating a need for more studies on reducing emissions through behaviour. This all harkens back to the nature of climate change, in that it is an issue at the global scale, requiring a multitude of solutions.

5.0.2 Behavioral Clusters

Put simply, the research objective of identifying usable behavioural clusters was not met. That said, the research question was somewhat answered just in an unexpected and incomplete manner. There is evidence that behavioural clusters which affect emissions exist, but the nature of these clusters is not apparent from this study leaving the usability of this knowledge to be very minimal. Knowing they exist does have inherit benefit as planners who are aware of behaviour clusters can begin looking for and identifying them in their work, allowing them to apply them in minor ways but to properly utilize behavioural clusters three things must be known: how behavioural clusters exist in a general fashion, how a planner can identify behavioural clusters in their jurisdictions and how to apply knowledge of behavioural clusters to planning policy.

In terms of the general nature of behavioural clusters, it is important to understand how likely it is for a behavioural cluster(s) to exist at any given scale, and how prolific they generally are will give a general idea of how planners can apply behavioural clusters. This is essentially the foundational knowledge which behavioural cluster application methods will be built on. It is clear that just like human behaviour, there are dimensions to these behavioural clusters that are not as intuitive as one might assume. Another uncertainty about these behavioural clusters is how prolific they are. While the evidence seems to suggest they are not common, the setting might be an exception rather than the general rule. This is important because more prolific behavioural clusters have more potential for application. While these unknowns might imply there is a chance behavioural clusters could be unusable by planners, it is likely that any form of behavioural cluster will be at least somewhat usable. This is because any additional understanding on behaviour helps understand how people will interact with the environment around them, in turn informing planners on how to design the built environment.

Next, once behavioural clusters are better understood, planners must learn how to identify and how to apply different kinds of behavioural clusters. This can be done both via research and via practical trial and error in the professional planning environment. All things considered, it was impossible to know just how deep the potential for behavioural cluster research was when designing this study. With hindsight, the research objective related to behavioural clusters was unobtainable.

5.0.3 Study-wide Linkages

While the studies of the two chapters may seem independent in terms of results and conclusions, compounded they further support the main objective of the overarching study. The short version is that the conclusion that behavioural clusters likely exist and likely affect emissions behaviours supports the feasibility of applying BERs on a larger scale. From studying net-zero communities, the conclusion is that PERs take precedent because of their large impact for a single method while behavioural can fill the gap. But by applying behavioural clusters, one intervention aimed at increasing behavioural emissions reductions can affect many behaviours, in turn having a larger impact. While in most cases, this will still leave physical methods with a higher impact, it means there will be some situations where, due to available resources, time efficiency or cost efficiency, behavioural methods will take precedent. In addition, behaviour clusters still help behavioural methods better fill the gaps left in cases where physical methods still take precedent. That being considered, in these situations more research will be needed than normal because the behavioural cluster must be suited and tailored to filling the physical gap; it would not be effective if the behavioural cluster only addressed emission sources which were already being reduced by the physical methods. That said, the analysed BERs, specifically those planners can easily target without the use of behavioural clusters, generally have less overlap with PERs.

While the conclusions reached by the study help prove the value and need for behavioural methods of emissions reductions in climate and planning research, no concrete conclusions were provided on the study regarding real world applications. Essentially, while the study attempted to provide a qualitative lens to support application purposes, the study was too broad to home in the reasoning behind emission reducing behaviour and behavioural clusters. Such questions might be better addressed by a focused qualitative study, with methods which allow for deeper understanding of the subject matter. This limits how usable these conclusions are for planners outside of future planning research. While planners certainly can consider how to affect BERs and begin looking for behavioural clusters, trying to apply these conclusions to planning application may be hasty without a full understanding of how to leverage these findings to effectively reduce emissions.

5.0.4 Planning Implications

Planners can practically and theoretically apply the results of this study to reduce emissions. On the practical and more specific side, planners can focus on reducing the need for motorized transportation. On the theoretical side, these results can be applied in a framework when utilizing planning policy and zoning considerations

First, because the greatest source of BERs was from personal transportation, if planners wish to directly affect city-wide emissions, the most effective way to do this would be to reduce the need for transportation. They can do this utilizing planning practices focused on creating walkable cities/communities. Planners can use existing planning concepts like the 15-min city to achieve this in drastic situations, or by altering zoning to be more varied in other situations. This method focuses on utilizing a physical change to induce a behavioural change in the population.

Based on the results of this study, planners also have a new framework to address emissions within their jurisdiction. The first step in this framework is identifying the best solutions for addressing, however based on past literature, this will likely include both behavioural and physical solutions (Chapman, 2007; Johansson, 2009; Wynes et al., 2018). Considerations for this should include what implementations are already in progress, sectors that require the most improvements and logistic limitations. Once the solutions are identified, both the behaviour and physical should be implemented simultaneously for time efficiency, however if limitations exist than behavioural solutions should be prioritized for faster implementation. Similarly, behavioural solutions can be used as a transitional solution or an emergency solution for relatively fast effects. Examples of quick, behaviour altering planning solutions are smaller changes to urban form, such as the introduction of walking paths, sidewalks and bike lanes and improved communication regarding city transportation options and alternatives, however this level of the framework would mostly be covered by other policy. Planners' main contributions would be towards the long term physical and long term behavioural emissions reductions via larger-scale changes to and withing the city. Once initial solutions have been implemented, another analysis should be done to address the gaps left by the solutions and the cycle should be repeated again, introducing newer behaviour and physical implementations that were developed since the initial analysis. This cycle allows planners to address emissions quickly and over a long time periods, while also addressing a wide range of emissions sources.

These behaviour solutions would theoretically focus on encouraging less motorized transportation based on the results of this study. However, there is still validity to behavioural solutions which overlap with physical solutions. This is because the binary definitions of this study removed the ability to measure overlapping solutions and because in a long-term/large-scale perspective this overlap is irrelevant. But, in cases where behaviour is being used as a transitional or speedy solution, this increases the efficacy of the behaviour solutions.

Appropriate larger-scale behaviour solutions in literature could include commercial rezoning for more accessible regular shopping needs such as groceries, more walkable cities and rezoning for less offices and increased remote work (Logan et al., 2022; Streimikiene, 2015). Meanwhile, appropriate physical solutions are zoning and planning for net-zero communities, or when more limited logistically, increasing developments for clean energy and incentives for retrofitting available for and targeted at parts of a city of higher concern with fewer options for improved urban form. An interesting note is that planners' tools and methods for affecting both physical and behavioural emissions reductions are mostly related to urban form. This matches the themes of the literature in that a planner's best tool for reducing emissions is altering urban form (Lee & Lee, 2014).

Ultimately the main takeaway for planners based on the results of this study is that behaviour can be used as a relatively fast and relatively cheap method to reduce household and, by extension, municipal greenhouse gas emissions. While technological improvements remain more consistent and stable methods of emission reductions, behaviour remains a notable but under looked method of planning intervention. The results of this study supports planners in their decisions because they show that not only are behavioural solutions theoretically a viable alternative, but are provably effective in practical environments.

5.0.5 Future Research Needs

Being designed as a foundational study on the subject of behavioural carbon emissions, there are many research gaps which future studies should address. Of the most importance is research to deepen the understanding of the subject. This is important because the understanding provided by this study is not well suited for application environments. The conclusions of this study say that planners can and should apply knowledge of behavioural emissions reductions and behaviour clusters to reduce emissions in their planning jurisdiction, but it does not inform a planner of how to do this except in vague and uncertain terms which are based on logical conclusion rather than proven research. This is especially a problem for behavioural clusters as the study concluded these clusters are not always intuitive which makes them difficult to deduce logically, leaving these clusters unknown and unusable. As such, future studies should determine why people choose options which create more/less GHG emissions, via focused qualitative studies and related methods, mixing in some quantitative methods when necessary to properly encompass the innately quantitative nature of carbon emissions. This would, in essence, be the opposite of this study, a qualitative focused study with some aspects of quantitatively due to the nature of behaviour. Future studies may also benefit from minor improvements to methodology. First, more concrete data collection such as monitoring rather than self-reported emissions statistics. These studies can also be deepened at the study background level by redefining physical and behavioural emissions reductions to better fit real life contexts, which will further add to the applicability of the study.

In terms of additional subject matter for future studies that are related to the secondary questions, first is considering future studies regarding net-zero technology. In this case, the conclusions of this study and past studies definitively prove the value of net-zero in a practical setting, so the next consideration is scalability. Future research on the subject should continue to focus on how to apply net-zero infrastructure realistically and effectively to a larger scale, i.e., the municipal scale. While literature currently focuses on technological aspects of increasing scalability, attention should also be given to non-technological factors (Johansson, 2009; Kromer er al., 2010; Lee & Lee, 2014; Morrow et al., 2010; Streimikiene & Volochovic, 2011; Wynes et al., 2018). Some consideration can be given to different geographic contexts and available renewable resources and should be able to draw the line at where concessions must be made to enable wide implementation at the cost of true net-zero. For behavioural clusters, there are fewer existing studies and the study concluded they are very context driven. As such, future studies could both be geographically broad to expand the subject matter or geographically specific so that the research has more application value. That being considered, a broader understanding of the subject matter would be valuable before trying to apply it, therefore future behavioural cluster research should first focus on broad contexts. Finally, future research could be done specifically on how planners can creatively affect behaviours and in turn emissions, particularly with the use of greenspaces or urban form.

5.0.6 Connections to Past Literature

Overall, this research echoes what is noted in more recent environmental research: that there is an opportunity for behavioural climate change solutions to have a significant effect on household emissions, in turn having a large effect on global emissions (Chapman, 2007; Johansson, 2009; Wynes et al., 2018). Ultimately, for reaching the goal of reaching global emission targets, not only is this opportunity possible but, as outlined by other researchers however not explored in this study, it is necessary (Streimikiene & Volochovic, 2011; Wynes et al., 2018). The exact quantities of greenhouse gas emission reductions were inconsistent between this research and other studies. Generally, this resulted in lower emissions from behavioural reductions when compared directly to what is estimated of behaviour in other studies (Dietz et al., 2009; Streimikiene & Volochovic, 2011). However, this study used a unique definition of BERs which accounts for this difference, which was stricter with what defines BERs and in a context that emphasized physical reductions over behavioural reductions (Dietz et al., 2009; Streimikiene & Volochovic, 2011). This means that in most practical applications and in typical communities, behavioural reductions will more closely resemble results from previous behavioural studies. BERs will resemble the results of this study in the long-term, after both behavioural and physical methods have been used, when overlapping emission reductions are being handled by physical improvements.

Behavioural cluster research has inconsistent findings. This study matched said studies in that the findings were inconclusive and could have used better sample sizes and/or methodology (Williden et al., 2012). There were some similarities, in that positive behaviours seemed to cluster less, with respondents focusing on a small set of emission improving behaviours rather than many or all behaviours (Olds et al., 2017; Reedy et al., 2005; Williden et al., 2012). Overall, this study did not find anything that was a large departure from past literature and simply expands the understanding of behaviour and emissions: into a practical environment, their interconnectedness, and into directions not fully explored. This further emphasizes the need for planners to research and understand behaviour to best serve their jurisdictions. What current literature lacks that this study indicates a further need for is a more holistic consideration and definition of behavioural changes, rather than just focusing on behaviours in a single category (ex. transportation, waste, electricity, etc.).

Chapter 6 – Thesis Conclusions

6.1 Summary of Key Findings

The study came to a variety of conclusions among the two different analyses, some more concrete than others. The most important findings are as follows:

- Under a binary definition of physical and behavioural emissions reductions, physical emissions reductions are quantitatively superior in their effectiveness by about 50% with potential variance depending on context, scale and effectiveness of behaviour;
- When applying net-zero infrastructure and when considering the value of applying it in a real-world setting, the ease of implantation and scalability are the most important considerations;
- While quantitively inferior, in the pursuit of an ideal zero emissions future, behavioural emissions reductions should be considered and applied especially because there is potential for them to change compared to the static reductions from physical reductions and when considering redundancy between physical and behavioural;
- Because behavioural reductions are dependant on individual choices, the key to implementation is information rather than awareness, because most people know and believe in climate change, but still engage in misinformed or unsustainable practices;
- While no concrete behaviour clusters were identified, evidence of behaviour clusters were found despite the limited capacity of the data which have some similarities to behaviour clusters in health-related fields;

- People generally only participate in a small number of emission reducing behaviours at a high effectiveness rather than many emission reducing behaviours at a lower effectiveness, which increases the possibility of potential behaviour clusters.
- Some patterns in behaviour were intuitive, while others were counter-intuitive, implying to fully understand behaviour and behavioural clusters, planners must research their targets rather than using logical inference;
- Planners can use these results for a framework which utilizes behaviour changes as a cheap/fast/transitional method for emissions reductions while physical changes are used for larger environmental impact;
- These results do not perfectly line up with past literature in the field or on related subjects, however are in line with said studies, showing both that behaviour changes are significant and that behaviours can cluster in somewhat understandable ways.

6.2 Future Studies and Research Needs

Future studies related to quantifying and comparing behavioural emissions reductions to physical emissions reductions should focus on improving the methodology, improving response rate and expanding the scope of studies, by studying additional geographic contexts and potentially by studying larger scales such as the city scale. It is also important for these studies to consider the definitions of physical and behavioural reductions, how to improve and expand these definitions to better apply to the real world, and the redundancy/overlap between which emissions sources they address. Future studies can also apply these theories and methods on other contexts, both inside planning, such as towards transportation or corporation analyses, and outside planning.

Studies related to green infrastructure desperately need more practical studies on new green infrastructure as they come up to support/disprove theoretical studies such that application of theoretical models such as a net-zero city can be considered. Otherwise, studies on net-zero infrastructure and their physical effects are adequately explored and can now be parsed out from behavioural effects. Instead, future research in regards to net-zero should focus on cost and attainability of wide spread implementation.

Finally, future studies on behavioural clusters should focus on broad samples and identifying many potential behavioural clusters. From there additional studies can apply the theories of behavioural emissions reductions to behavioural clusters and quantify the clusters and their effects. Behavioural clusters also have wider application on other fields depending on results and can be adapted to other application type studies once they have been probed out.

References

Agrawal A. & Lemos, M. (2015). Adaptive development. *Nature Climate Change, 5*(3), 185-187.

Ayylidiz, E. & Erdogan, M. (2022). Identifying and prioritizing the factors to determine best insulation material using Bayesian best worst method. *Proceedings of the Institution of Mechanical Engineering, Part E: Journal of Process Mechanical Engineering, 2022*, 95440892211115.

Bakhtavar, E., Prabatha, T., Karunathilake, H., Sadiq, R. & Hewage, K. (2020). Assessment of renewable energy-based strategies for net-zero energy communities: A planning model using multi-objective goal programming. *Journal of Cleaner Production, 272*, 122886.

Boies, A., Hankey, S., Kittelson, D., Marshall, J., Nussbaum, P., Watts, W. & Wilson, E. (2009). Reducing Motor Vehicle Greenhouse Gas Emissions in a Non-California State: A Case Study of Minnesota. *Environmental Science and Technology, 43*(23), 8721-8729.

Bucking, S., & Cotton, J. (2015) Methodology for energy and economic modeling of net zero energy communities. *ASHRAE Transactions, 121*(1), 462-470.

Chapman, L. (2007). Transport and climate change: a review. *Journal of Transport Geography, 15*, 354-367.

Chen, G., Shan, Y., Hu, Y., Tong, K., Wiedmann, T., Ramaswami, A., Guan, D., Shi, L. & Wang, Y. (2019). Review on City-Level Carbon Accounting. *Environmental Science and Technology, 53*, 5545-5558.

City of London. (2021). *2020 Community Energy Use & Greenhouse Gas Emissions Inventory*. https://ehq-production-canada.s3.ca-central-1.amazonaws.com/dc3316af3a624af675e3776d7cef773769823177/original/1629915971/30ef70acf2fe76cd9ac6c406af2bd952_2020_Inventory_Report_final.pdf

Dietz, T., Gardner, G., Gilligan, J., Stern, P. & Vandenbergh, M. (2009). Household actions can provide a behavioral wedge to rapidly reduce US carbon emissions. *Proceedings of the National Academy of Sciences, 106*(44), 18452-18456.

Duarte, R., Rebahi, S., Sanchez-Choliz, J. & Sarasa C. (2014). Household's behaviour and environmental emissions in a regional economy. *Economic Systems Review, 26*(4), 410-430.

Elizondo, A., Perez-Cirera, V., Strapasson, A., Fernandez J. & Cruz-Cano, D. (2017). Mexico's low carbon futures: An integrated assessment for energy planning and climate change mitigation by 2050. *Futures, 93*, 14-26.

Environment Climate Change Canada [ECCC]. (2021). *National inventory report : greenhouse gas sources and sinks in Canada. https://publications.gc.ca/collections/collection_2023/eccc/En81-4-2021-1-eng.pdf*

Environment Climate Change Canada. (2022). *Global Greenhouse Gas Emissions Canadian Environmental Sustainability Indicators*. https://www.canada.ca/content/dam/eccc/documents/pdf/cesindicators/global-ghg-emissions/2022/global-greehouse-gas-emissions-en.pdf

Fujimoto, T., Yamaguchi, Y. & Shimoda, Y. (2017). Energy management for voltage control in a net-zero energy house community considering appliance operation constraints and variety of households. *Energy and Buildings, 147*, 188-199.

Girod, B., Van Vuuren, D. & Hertwich, E. (2014). Climate policy through changing consumption choices: Options and obstacles for reducing greenhouse gas emissions. *Global Environment Change, 25*, 5-15.

Gooch, M., Matsubuchi-Shaw, M., Bucknell, D., LaPlain, D. & Kohler, L. (2022). Quantifying the carbon footprint of household food waste and associated GHGs in Oakville, Ontario, and a municipality's role in reducing both food waste and GHGs. *Canadian Geographies/Géographies canadiennes, 66*(4), 769-782.

Guo, L., Liu, Y., Zhu, Y. & Wei, M. (2020). Identification of health behaviour clusters among people at high risk of stroke: A latent class profile analysis. *Journal of Advanced Nursing 76*(11), 3039-3047.

Hammett, L., Worzala, E. & Springer, T. (2018). The Devastating Impact of Storm Surge on Coastal Communities: A Case Study on Florida's Low Income Housing Tax Credit Projects. *Real Estate Issues, 42*(12), 1-12.

Higgins, A., Foliente, G. & McNamara, C. (2011). Modelling intervention options to reduce GHG emissions in housing stock — A diffusion approach. *Technological Forecasting and Social Change, 78*(4), 621-634.

Johansson, B. (2009). Will restrictions on CO_2 emissions require reductions in transport demand. *Energy Policy, 37*, 3212-3220.

Jones, C. & Kammen, D. (2011). Quantifying Carbon Footprint Reduction Opportunities for U.S. Households and Communities. *Environmental Science and Technology, 45*, 4088-4095.

Joosen, S. & Blok, K. (2001). *Economic Evaluation of Carbon Dioxide Emission Reduction in the Household and Services Sectors in the EU: Bottom-up Analysis* (Final Report). Ecofys.

Karunathilake, H., Hewage, K., Mérida, W. & Sadiq, R. (2019). Renewable energy selection for net-zero energy communities: Life cycle based decision making under uncertainty. *Renewable Energy, 130*, 558-573.

Kim, M., Kim, D., Heo., J & Lee, D. (2019). Techno-economic analysis of hybrid renewable energy system with solar district heating for net zero energy community. *Energy, 187*, 115916.

Kromer, M., Bandivadekar, A. & Evans, C. (2010). Long-term greenhouse gas emission and petroleum reduction goals: Evolutionary pathways for the light-duty vehicle sector. *Energy, 35*, 387-397.

Larsen, H. & Hertwich, E. (2009). The case for consumption-based accounting of greenhouse gas emissions to promote local climate action. *Environmental Science and Policy, 12*(7), 791-798.

Lau, C. (2022). From Grey to Green: Transforming Abandoned, Redundant, or Unwanted Infrastructure Into Parks. *Public Works Management and Policy, 28*(1), 53-69.

Lee, S. & Lee, B. (2014). The influence of urban form on GHG emissions in the U.S. household sector. *Energy Policy, 68*, 534-549.

Lemos, M. & Agrawal, A. (2006). Environmental governance. *Annual review of environment and resources, 31*(1), 297-325.

Lindon, W. (2014). *Bayesian probability theory : applications in physical sciences*. Cambridge : Cambridge University Press.

Logan, T., Hobbs, M., Conrow, L., Reid, N., Young, R. & Anderson M. (2022). The x-minute city: Measuring the 10, 15, 20-minute city and an evaluation of its use for sustainable urban design. *Cities, 131*, 103924.

Mai, R. & Hoffman, S. (2012). Taste lovers versus nutrition fact seekers: How health consciousness and self-efficacy determine the way consumers choose food products. *Journal of Consumer Behaviour, 11*, 316-328.

Meiklejohn, D., Bekessey, S. & Moloney, S. (2018). Shifting practices: How the rise of rooftop solar PV has changed local government community engagement. *Cogent Environmental Science, 4*(1), 1481584.

Meiklejohn, D., Moloney, S. & Bekessey, S. (2021). Applying a Practical Lens to Local Government Climate Change Governance: Rethinking Community Engagement Practices. *Sustainability, 13*(2), 995.

Morrow, W., Gallagher, K., Collantes, G. & Lee, H. (2010). Analysis of policies to reduce oil consumption and greenhouse-gas emissions from the US transportation sector. *Energy Policy, 38*(3), 1305-1320.

Natural Resources Canada. (2018). *West 5 Smart Grid Project*. https://natural-resources.canada.ca/science-and-data/funding-partnerships/opportunities/current-investments/west-5-smart-grid-project/22880

Niamir, L., Ivanova, O. & Filatova, T. (2020). Economy-wide impacts of behavioral climate change mitigation: Linking agent-based and computable general equilibrium models. *Environmental Modelling and Software, 134*, 104839.

Nikravech, M., Kwan, V., Dobernig, K., Wilhem-Rechmann, A. & Langen, N. (2020). Limiting food waste via grassroots initiatives as a potential for climate change mitigation: a systematic review. *Environmental Research Letters, 15*, 123008.

Olds, T., Sanders, I., Maher, C., Fraysse, F., Bell, L. & Leslie, E. (2017). Does compliance with healthy lifestyle behaviours cluster within individuals in Australian primary school-aged children? *Child: Care, Health and Development, 44*(1), 117-123.

Onat, N., Kucukvar, M. & Tatari, O. (2014). Scope-based carbon footprint analysis of U.S. residential and commercial buildings: An input–output hybrid life cycle assessment approach. *Building and Environment, 72*, 53-62.

Porras, G., Keoleian, G., Lewis, G. & Seeba, N. (2020). A guide to household manual and machine dishwashing through a life cycle perspective. *Environmental Research Communications, 2*, 021004.

Reames, T. (2016). A community-based approach to low-income residential energy efficiency participation barriers. *Local Environment, 21*(12), 1449-1466.

Reedy, J., Haines, P. & Campbell, M. (2005). The influence of health behavior clusters on dietary change. *Preventative Medicine, 41*(1), 268-275.

Schifman, L., Herrmann, D., Shuster, W., Ossola, A., Garmestani, A. & Hopton, M. (2017). Situating Green Infrastructure in Context: A Framework for Adaptive Socio-Hydrology in Cities. *Water Resources Research, 53*(12), 10139-10154.

Seto, K., Churkina G., Hsu, A., Keller, M., Newman, P., Qin, B. & Ramaswami, A. (2021). From Low- to Net-Zero Carbon Cities: The Next Global Agenda. *Annual Review of Environment and Resources, 46*, 377-415.

Shahmohammadi, S., Steinmann Z., Clavreul, J., Henickx, H., King, H. & Huijbregts, M. (2017). Quantifying drivers of variability in life cycle greenhouse gas emissions of consumer products—a case study on laundry washing in Europe. *The International Journal of Life Cycle Assessment, 23*, 1940-1949.

Shahmohammadi, S., Steinmann Z., King, H., Henickx, H., & Huijbregts, M. (2019). The influence of consumer behavior on energy, greenhouse gas, and water footprints of showering. *Journal of Industrial Ecology, 23*(5), 1186-1195.

Shandiz, S., Rismanchi, B. & Foliente, G. (2021). Energy master planning for net-zero emission communities: State of the art and research challenges. *Renewable Energy and Sustainable Energy Reviews, 137*, 110600.

Sifton Corporation. (2019). *Category Archives: News*. Retrieved from https://west5.ca/category/news.

Spoerri, A., Lang, D., Binder, C. & Schloz, R. (2009). Expert-based scenarios for strategic waste and resource management planning—C&D waste recycling in the

Canton of Zurich, Switzerland. *Resources, Conservation and Recycling, 53*(10), 592-600.

Streimikiene, D. & Volochovic, A. (2011). The impact of household behavioral changes on GHG emission reduction in Lithuania. *Renewable and Sustainable Energy Reviews, 15*(8), 4118-4124.

Streimikiene, D. (2015). Assessment of reasonably achievable GHG emission reduction target in Lithuanian households. *Renewable and Sustainable Energy Reviews, 52*, 460-467.

Thompson, J. & Krarti, M. (2021). Cost-Effectiveness and Resiliency Evaluation of Net-Zero Energy U.S. Residential Communities. *Journal of Engineering for Sustainable Buildings and Cities, 2*(3), 031002.

Tukker, A., Pollitt, H. & Henkemans, M. (2020). Consumption-based carbon accounting: sense and sensibility. *Climate Policy, 20*(S1), S1-S13.

Twisk, D. & Senserrick, T. (2021). Risky road behaviours cluster and share predictor variables with smoking and drinking, and anti-social behaviours during early adolescence. *Journal of Transport & Health, 20*, 101024.

Verger, P., Lions, C. & Ventelou, B. (2009). Is depression associated with health risk-related behaviour clusters in adults? *European Journal of Public Health, 19*(6), 618-624.

Vindel, E., Berges, M. & Akinci, B. (2019). Energy sharing through shared storage in net zero energy communities. *Journal of Physics: Conference Series, 1343*, 12107.

Wang, S. & Chen, B. (2018). Three-Tier carbon accounting model for cities. *Applied Energy, 229*, 163-175.

Williams, P. (2018, Mar. 8). *Ontario's first sustainable net-zero community shaping up in London*. Daily Commercial News. Retrieved from https://canada.constructconnect.com/dcn/news/projects/2018/03/ontarios-first-sustainable-net-zero-community-shaping-london

Williden, M., Duncan, S. & Schofield, G. (2012). Do health behaviours cluster in a working population in New Zealand?. *Health Promotion Journal of Australia, 23*(3), 234-236.

Wynes, S., Nicholas, K., Zhao, J. & Donner, S. (2018). Measuring what works: quantifying greenhouse gas emission reductions of behavioural interventions to reduce driving, meat consumption, and household energy use. *Environmental Research Letters, 13*(11), 113002.

Young, J. & Brans, M. (2017). Analysis of factors affecting a shift in a local energy system towards 100% renewable energy community. *Journal of Cleaner Production, 169*, 117-124.

Young, W., Russell, S., Robinson, C. & Barkemeyer, R. (2017). Can social media be a tool for reducing consumers' food waste? A behaviour change experiment by a UK retailer. *Resources, Conservation and Recycling, 117*, 195-203.

Zhivov, A., Kimman, J., Case, M., Broers, W. & Liesen, R. (2014). Energy master planning towards net-zero energy communities/campuses. *ASHRAE Transactions, 120*(1), 115-129.

Appendix 1: Survey Introduction Letter

**Exact formatting may differ from original due to section title*

Hello,

My name is Joshua/PersonGuy Hu and I am a graduate student in the University of Waterloo's School of Planning under the supervision of Professor Jeremy Pittman. I am doing research on greenhouse gas emissions as they relate to choices and environmental awareness. I am also comparing these to how they compare to greenhouse gas emission reductions from improved infrastructure (ex. more energy efficient appliances). To do this, I am surveying similar town house complexes in London. This study has been reviewed and received ethics clearance through a University of Waterloo Research Ethics Board. Further context and information are contained in the survey information page.

This survey package contains the following:

- Introduction letter (which you are currently reading)
- Study information sheet
- A physical copy of the survey
- Return postage and return address sticker

This survey will take less than fifteen minutes and will not ask for any personal identifying information such as the name of anyone in your household. You will be asked questions that are related to your environmental awareness, your environmental behaviour and your household carbon emissions. Your address will not be tied to your responses and your individual answers will not be released in any manner. All questions are completely optional. To complete all the questions, you will need access to the following:

- Gas and Electric Bills for up to 12 months
- Energy Efficiency of the following appliances:
  - Refrigerator, Dishwasher, Stove/Over Cooktop, Washing Machine, Dryer, Microwave

Your data may help: improve how governments spend money on environmental initiatives, reduce taxes and reduce carbon emissions. You can complete the attached physical copy of this survey (return postage and address included) or you can fill out the online version which is identical (link and QR code attached to top of physical survey). **Please only fill out one of the two**. Please fill out or return the survey by October 31, 2021. Due to the nature of the research, you will be asked to make some estimates and I ask that you be as accurate as you can.

Thank you for your consideration. If you have any questions, comments or are interested in the findings, feel free to send me an e-mail at joshu@uwaterloo.ca. I wish you the best.

Excelsior,

PersonGuy Hu

Graduate Student
School of Planning,
University of Waterloo

Appendix 2: Study Information Sheet (sent with survey)

**Exact formatting may differ from original due to section title*

Study Information Sheet

Study Name:

Faculty Supervisor:
Jeremy Pittman, PhD
School of Planning
University of Waterloo
jpittman@uwaterloo.ca
519-888-4567 ext. 41544

Student Investigator:
Joshua/PersonGuy Hu, BEs
School of Planning
University of Waterloo
joshu@uwaterloo.ca

Ethics Clearance: This study has been reviewed and received ethics clearance through a University of Waterloo Research Ethics Board (REB #43613).

If you have questions for the Board contact the Office of Research Ethics, at 1-519-888-4567 ext. 36005 or reb@uwaterloo.ca.

What is this Study About

Most climate change research is focused on how technology can be improved to reduce carbon emissions. Not enough attention has been given to the exact, numeric effects of behaviour changes on carbon emissions such as recycling more. The purpose of this study is to provide a concrete number for carbon emissions reduced from changing behaviours and compare that to carbon emissions from better technology in a realistic setting. Related to that, this study will try to find out how environmental awareness can impact these behaviours resulting in behavioural emission reductions.

What is the Purpose of this Study

1) To quantify the emission increases/decreases as a result of household choices.
2) To determine why people make choices which affect greenhouse gas emissions.
3) To determine how much behavioural emissions can influence global emissions compared to physical emission
4) To determine if environmental infrastructure is worth increased investments from municipal governments.

How will the purposes be met?

To meet the four purposes listed above, two communities with different levels in the city of London are being surveyed. One community is the West 5 Townhomes net-zero community, which is green infrastructure designed to reduce emissions, and the other is a typically built neighbourhood, Towns in Hyde Park. By surveying different aspects of your household that may affect carbon emissions and categorizing them as a result of choices and improved technology, purposes 1 and 3 can be met. From questions and characteristics related to environmental attitude, purpose two will be discovered. Finally, purpose four will be met by associating the emissions found in purpose three with implementation costs from other research.

Why is this Study Important

This study may improve future environmental policy research. These types of study may eventually help policy makers better allocate money towards environmental initiatives. This survey may help determine if infrastructure changes, such as net-zero communities, have any effect on behaviours which may help us create more effective and creative climate change solutions. This may also help city planners see just how effective sustainable infrastructure is.

Your Responsibilities as a Participant

Participation in this study entails completion of a single 15 min survey. This study will collect information on your environmental awareness and behaviours. It will also collect information on your home's infrastructure to quantify your emissions. You will be asked to look up gas and electric usage from past bills and the energy efficiency of your home appliances. This will improve the accuracy of the survey however, like all questions in this survey, these questions can be skipped. The questions asked will be mostly numeric or multiple choice, with sections in which you can elaborate on your answers if you wish.

You may complete the study by an online survey operated by Qualtrics. Qualtrics has implemented technical, administrative, and physical safeguards to protect the information provided from loss, misuse, and unauthorized access, disclosure, alteration, or destruction. However, no internet transmission is ever fully secure or error free. Qualtrics temporarily collects your computer IP address to avoid duplicate responses in the dataset but will not collect information that could identify you personally.

If you prefer, you may instead complete the study via paper survey which is included with the survey package. This can be sent back with the included postage and return address. Personal information included as a result of the process of mailing (i.e. return address) will not be tied to the survey results, anonymizing the data.

Your Rights as a Participant

Participation in this study and all questions with this study are voluntary. There are no known or anticipated risks associated with participation in this study. You may skip any question in the survey, both online and physical, by leaving the question blank. You may leave the study at anytime by not submitting/mailing back the survey. It is not possible to remove your data from the study once collected because data is anonymous and all potentially identifying information is removed from the data immediately.

Data is anonymous by not asking any questions which could identify an individual. Mail-in surveys could contain identifying personal information, such as return address, however this will be separated from the associated completed survey and the envelope will be immediately destroyed. Data from the survey will be retained for at least one year after the completion of the study on a secure University of Waterloo server. The study is expected to be completed in April of 2022.

You will not receive remuneration for your participation in the study however there are various indirect benefits and benefits to society. This study can help improve policy and government spending in relation to greenhouse gas emissions and environmental infrastructure, indirectly benefitting all tax players, yourself included. There are also benefits to environmental and urban planning academia.

As a participant, you have the right to request the results of the study. If you would like to receive a summary of the study findings, please email the student investigator using the contact information at the top of the sheet, which will be sent at the earliest possible convenience. Any questions you may also contact either of the investigators.

Appendix 3: Complete Survey

**Exact formatting may differ from original due to section title*

Survey on Household Carbon Emissions

Some questions are not as important and are only to help improve accuracy or provide context and are marked like so: [+].

Online survey link:
https://uwaterloo.ca1.qualtrics.com/jfe/form/SV_2s39YeiDtTFGpDg

---

Start of Block: Consent

I have read the information presented in the information letter about a study being conducted by Joshua/PersonGuy Hu of the School of Planning at the University of Waterloo. I have had the opportunity to ask any questions related to this study, to receive satisfactory answers to my questions, and any additional details I wanted. I am aware that after completion I am unable to withdraw from the study due to the anonymous nature of the data.

This study has been reviewed and received ethics clearance through a University of Waterloo Research Ethics Board (REB #43613). If you have questions for the Board contact the Office of Research Ethics, at 1-519-888-4567 ext. 36005 or reb@uwaterloo.ca. For all other questions contact Joshua/PersonGuy Hu at joshu@uwaterloo.ca.

By checking yes I agree to the above and provide my consent for the information in this survey to be used in this study.

○ Yes

○ No

End of Block: Consent

Start of Block: Demographic Questions

Q1.1 How many people do you have in your household?

____

Q1.2 How many members of your household are above the age of 21?

____

End of Block: Demographic Questions

Start of Block: Starting Questions

Q2.1 Do you support carbon taxes?

○ Yes

○ No

Q2.2
Why do you support carbon taxes?

(Choose all that apply)

- ☐ They are beneficial for the environment
- ☐ They are an effective means of lowering carbon emissions
- ☐ They improve air quality
- ☐ They reduce traffic congestion
- ☐ They promote environmental awareness
- ☐ I do not support carbon taxes for any reason
- ☐ Other (please specify) ________________

Q2.3
Why don't you support carbon taxes?

(Choose all that apply)

- ☐ They are too expensive
- ☐ They increase the price of essential goods/services
- ☐ They create inequalities between high and low income households
- ☐ They are unnecessary
- ☐ They are not an effective means of lowering carbon emissions
- ☐ I completely support carbon taxes
- ☐ Other (please specify) ____

Q2.4 [+]: If you would like, please elaborate on any of your answers above.

____

____

____

____

____

End of Block: Starting Questions

Start of Block: Climate Change Opinions

Q3.1 Rate your agreement with the following statements.

	Strongly Disagree	Somewhat Disagree	Neither Agree Nor Disagree	Somewhat Agree	Strongly Agree
I believe climate change exists	○	○	○	○	○
I believe climate change is a big issue.	○	○	○	○	○
I want to stop/slow climate change.	○	○	○	○	○
I am concerned about climate change as a whole.	○	○	○	○	○
I am concerned about the environmental effects of climate change.	○	○	○	○	○
I am concerned about the economic effects of climate change.	○	○	○	○	○
I am concerned about the social effects of climate change.	○	○	○	○	○

I think about the effects of climate change often.	○	○	○	○	○
I try to reduce my contribution to climate change.	○	○	○	○	○
I actively try to reduce my greenhouse gas emissions.	○	○	○	○	○
I keep myself informed on how I can reduce my carbon footprint.	○	○	○	○	○
I try to inform others on ways they can reduce their carbon footprint.	○	○	○	○	○
I have made lifestyle changes which have reduced my carbon footprint.	○	○	○	○	○
I feel responsible for helping reduce climate change.	○	○	○	○	○

I pay attention to news and developments regarding climate change.	○	○	○	○	○

Q3.2 [+]: If you would like, please elaborate on any of your answers above.

____

____

____

____

____

End of Block: Climate Change Opinions

Start of Block: Energy Usage

Q4.1
How much natural gas did you use in the past twelve months?

(Fill in as many months from the past year as possible. You can find this on your monthly gas bill in m3. If you cannot find the volume, provide the $ cost instead.)

- ○ January ________________________________
- ○ February ________________________________
- ○ March ________________________________
- ○ April ________________________________
- ○ May ________________________________
- ○ June ________________________________
- ○ July ________________________________
- ○ August ________________________________
- ○ September ________________________________
- ○ October ________________________________
- ○ November ________________________________
- ○ December ________________________________

Q4.2
How much electricity did use in the past twelve months?

(Fill in as many months from the past year as possible. You can find this on your monthly electric bill in kWh. If you cannot find the volume, provide the $ cost instead.)

- ○ January ____
- ○ February ____
- ○ March ____
- ○ April ____
- ○ May ____
- ○ June ____
- ○ July ____
- ○ August ____
- ○ September ____
- ○ October ____
- ○ November ____
- ○ December ____

Q4.3 In a percentage, approximately how many lightbulbs in your house are: fluorescent vs incandescent?

- ○ Fluorescent (%) ____
- ○ Incandescent (%) ____
- ○ Other (%) ____

Q4.4
[+]: What is the energy efficiency of your appliances?

(list as many appliances which you can locate the kWh's as possible)

- ○ Refridgerator ____
- ○ Dishwasher ____
- ○ Stove/Oven Cooktop ____
- ○ Washing Machine ____
- ○ Dryer ____
- ○ Microwave ____
- ○ Other (please specify) ____

Q4.5 [+]: Approximately how many loads of laundry do you do a week?

____

Q4.6 [+]: Do you air dry your laundry? If so, what percentage do you air dry (vs. machine dry)?

- ○ Yes (Enter percent below) ____
- ○ No

Q4.7 [+]: What is the average temperature you set your thermostat to in the summer and in the winter?

- ○ Summer ____
- ○ Winter ____

End of Block: Energy Usage

Start of Block: Waste Diversion

Q5.1 How comfortable are you with sorting your waste?

- ○ 1: Extremely uncomfortable, I do not know what can and can't be recycled, composted, etc.
- ○ 2: Somewhat uncomfortable
- ○ 3: Neither comfortable nor uncomfortable
- ○ 4: Somewhat comfortable
- ○ 5: Extremely comfortable, I always know which bin to put my waste in

Q5.2 Do you use a waste sorting guide like the Recycling Coach App?

- ○ Yes
- ○ No

Q5.3 How would you sort the following waste?

	Garbage	Paper Recycling	Container Recycling	Green Bin
Construction Paper	○	○	○	○
Milk and Juice Cartoons	○	○	○	○
Egg Cartoons	○	○	○	○
Soda Can	○	○	○	○
Styrofoam	○	○	○	○
Food Waste	○	○	○	○
Plastic Cutlery	○	○	○	○
Paper Towel	○	○	○	○

Q5.4
On average, how many bins of the following waste do you put out on collection days?
(Do not round. If you fill approx. half a bin of garbage answer "0.5")

○ Garbage Bins (90L) ____

○ Paper Blue Bin (65L) ____

○ Container Blue Bin (65L) ____

End of Block: Waste Diversion

Start of Block: Food Consumption

Q6.1 Do you purchase local food, and if so what percentage of food do you buy local?

- ◯ Yes (enter percentage below)

  ____

- ◯ No

Q6.2 What food types do you purchase locally?

- ◯ Meat
- ◯ Vegetables
- ◯ Fruit
- ◯ Animal Products (ex. dairy, eggs)
- ◯ Other (please specify) ____

Q6.3
OPTIONAL: What are the main influences in choosing what food to buy?
(Choose up to 3)

- ◯ Price
- ◯ Nutritional Value
- ◯ Taste
- ◯ Cravings
- ◯ Brand Name
- ◯ Certifications (ex. fair trade certified, etc.)
- ◯ Other (please specify) ____

Q6.4
OPTIONAL: On average, how much of the food do you buy gets thrown away?
(Answer in a percentage of total food bought in a week)

____

End of Block: Food Consumption

Start of Block: Transportation

Q7.1
On an average summer week, how far do you travel using each of the following methods of transportation?
(Do not include recreational purposes ex. cycling for fun/exercise)
(You may answer in any unit of distance or time but please specify unit in your answer)

- ○ Walking ____
- ○ Cylcing ____
- ○ Driving ____
- ○ Public Transit ____
- ○ Other (please specify with answer) ____

Q7.2
On an average winter week, how far do you travel using each of the following methods of transportation?
(Do not include recreational purposes ex. cycling for fun/exercise)

(You may answer in any unit of distance or time but please specify unit in your answer)

- ○ Walking ____
- ○ Cylcing ____
- ○ Driving ____
- ○ Public Transit ____
- ○ Other (please specify with answer)

____

Q7.3
What automobile(s) do you drive?
(If you own multiple of the same type please indicate with a number under the vehicle type)

- ☐ Gas Car ____
- ☐ Electric Car ____
- ☐ Hybrid Car ____
- ☐ Van/SUV/Large Car ____
- ☐ Pick-up Truck ____
- ☐ Motorcycle ____
- ☐ Other (please specify)

____

Q7.4 If you own multiple vehicles, what percentage of the time do you drive each vehicle?

____

Q7.5 OPTIONAL: What is the exact make and model of your vehicle(s)?

____

Q7.6
OPTIONAL: What is the gas mileage on your vehicle(s)?

____

Q7.7
What are the most important factors in choosing whether or not to drive to a location? (Choose up to 2)

- ▢ Distance
- ▢ Gas Prices
- ▢ Environmental Impact
- ▢ Urgency
- ▢ Weather
- ▢ I always drive regardless
- ▢ Other (please specify) ____

Q7.8
What are the most important factors in choosing a vehicle?

(Choose up to 3)

- ☐ Gas Mileage
- ☐ Appearance
- ☐ Brand
- ☐ Handling
- ☐ Safety
- ☐ Price
- ☐ Environmental Impact
- ☐ Other (please specify) ________________

End of Block: Transportation