

Assessing the Economic Viability of Nature-Based Solutions as an Urban Heat Island Mitigation
Strategy: A Framework for York Region

by

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A thesis
presented to the University of Waterloo
in fulfillment of the
thesis requirement for the degree of

Master of Environmental Studies

in

Sustainability Management

Waterloo, Ontario, Canada, 2025

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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

This thesis examines the economic viability of urban greenery cover (GC) as an urban heat island (UHI) mitigation strategy for York Region, Ontario. In light of increasing urban temperatures and intensifying heat stress, including the UHI effect, a comprehensive cost-benefit analysis (CBA) framework is developed to evaluate two distinct GC scenarios (moderate and intense). The analysis integrates a range of direct benefits – such as reduced emergency department visits, avoided premature mortality, decreased energy consumption, and increased productivity – alongside indirect benefits including improved air quality and enhanced biodiversity. A key innovation in this thesis is the incorporation of a non-linear tree canopy scaling factor into the benefit valuation process, recognizing that urban tree benefits, such as air quality and those resulting from cooling effects, do not accrue at a constant rate. The study applied a quadratic scaling function to reflect the gradual maturation of tree canopies over a 40-year project horizon. This adjustment enables a more accurate projection of economic returns by emphasizing the higher benefits realized as trees reach full maturity. Cost components, including initial installation and ongoing maintenance expenses, are also discounted at an annual rate of 3%, following established regulatory guidelines. Overall, the results demonstrate that both GC scenarios yield negative net present values (NPV) and benefit-cost ratios (BCR) of 0.01. However, when non-linear scaling is incorporated, the timing and magnitude of benefits are more accurately projected, reflecting ecological phenomena in an economic model. These findings not only advance the methodological framework for assessing the economic viability of nature-based solutions (NbS) in urban environments but also offer practical insights for policymakers and urban planners seeking to justify investments in urban GC as a means of mitigating the UHI effect and adapting to climate change.

Keywords: Climate Change Adaptation; Urban Greenery; Cost-Benefit Analysis; Tree Canopy Scaling; Nature-Based Solutions; Urban Heat Island; Economic Valuation

Acknowledgements

I would like to express my gratitude to my supervisor, Jeffrey Wilson, for his dedication and gracious support throughout my degree and writing process. He showed great patience and kindness as I dealt with many struggles and health issues along the way. Yet, he encouraged my perseverance. I would also like to thank the members of the Terrametrics Research Team for their inspiration and support. Particularly, I extend my heartfelt appreciation to Mohamed Dardir for his contributions to my research as well as his time and guidance in the research process. This thesis would not have been made possible without his mentorship and the data provided. Additionally, I must extend my gratitude to the wonderful professors and instructors in the faculty of Environment who show unwavering dedication and passion for their research and the education of all those enrolled. Furthermore, I would like to thank the University of Waterloo, TD Bank, Graduate Studies Endowment Fund, and the generous donors who made the Walter Metzger Memorial Award and Bob Graham Memorial Scholarship possible. Their financial awards played a vital role in the completion of this thesis.

On a personal level, I would also like to express my gratitude to my partner, Michael Eickhoff, who was a sounding board for my research ideas, a calming presence, and the most encouraging partner one could ever ask for. Finally, I extend my warmest regards and appreciation to London Health Sciences Centre (LHSC) and Epilepsy South Central Ontario (ESCO). In particular, I must thank the neurologist, Dr. Mirsattari, who diagnosed my brain tumor and advocated for an innovative and speedy brain surgery in August of 2022, allowing me to begin this program. If it were not for him and the support provided by LHSC and ESCO, this thesis would not have been possible.

Thank you!

Dedication

With love, I dedicate this thesis to my grandfather,

Gerd Hilgenberg,

a fellow University of Waterloo Alumnus.

Known for his reliability, practicality, and dedication to others.

A gift to his local community, to many students as a teacher, and his family, including myself.

He is a remarkably patient and kind man

who has stood by me and encouraged me

through all my life journeys –

the good and the bad.

Whether it was tutoring me in calculus,

driving me to rehabilitation after brain surgery,

listening to my presentations,

or having some laughs while playing crokinole to help me relax.

His support has been unwavering.

I dedicate this thesis to him with love and gratitude for all that he is.

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List of Abbreviations

CAD – Canadian Dollars

BCR – Benefit Cost Ratio

CIHI – Canadian Institute for Health Information

DOE - Department of Energy

EB – Economic Benefits

ES – Ecosystem Service(s)

EMR – Emergency Department Visits

GC – Greenery Cover

GHG – Greenhouse Gas

GTA – Greater Toronto Area

GTHA – Greater Toronto Hamilton Area

GVC – Ground Vegetation Cover

IPCC – Intergovernmental Panel on Climate Change

IUCN – International Union for Conservation of Nature

NbS – Nature Based Solution(s)

NPV – Net Present Value

OEB – Ontario Energy Board

PDA – Planting Delivery Agents

PV – Present Value

TC – Tree Cover

UHI – Urban Heat Island

UGS – Urban Green Space

US – United States of America

Chapter 1: Introduction

1.1 Background

Urban areas are facing unprecedented challenges as anthropogenic climate change escalates. Examples of observed changes include extreme weather events, increasing ambient temperatures, and heatwaves (Intergovernmental Panel on Climate Change [IPCC], 2021). Cities, where over half of the global population resides, are expected to continue growing and are highly vulnerable to climate change (IPCC, 2018, 2023). This is in part due to the amplified effects caused by the urban heat island (UHI) effect – a phenomenon where concrete, asphalt, and high-density human activities contribute to significantly higher local temperatures compared to surrounding rural areas (Deilami et al., 2018; Rizwan et al., 2008; L. Yang et al., 2016). Projections indicate that hot days with temperatures above 30°C are expected to more than triple by 2050 in the Greater Toronto Area (GTA) of Southern Ontario (Canada, 2011; Toronto Public Health, 2022), underscoring the urgent need for effective adaptive and mitigative strategies to safeguard urban communities.

The UHI effect and extreme heat events have serious consequences for public health and human wellbeing. Exposure to extreme heat is known to have both immediate and long-term health impacts. For example, increased risk of mental health issues, adverse pregnancy and birth outcomes, as well as cardiovascular and respiratory diseases, have all been observed (Ebi et al., 2021). Already escalating morbidity and mortality rates are projected to increase with expected higher temperatures and increased occurrence of heat waves due to climate change (Deilami et al., 2018; Ebi et al., 2021). In addition to health issues that are known to lead to increased emergency department visits, there is also an increase in heat-related mortality (Basagaña et al., 2011; Ebi et al., 2021). Heat waves/heat extremes are a major weather-related cause of death in high-income countries (Ebi et al., 2021). In Canada, extreme heat is the number one weather-related cause of death (Environment and Climate Change Canada, 2022b). An alarming example of this was the sudden three-fold increase in mortality counts in British Columbia, Canada, stemming from the 2021 heatwave that resulted in 619 fatalities (Environment and Climate Change Canada, 2022b; Henderson et al., 2022). These studies highlight the essential need to comprehend, adapt, and mitigate the impacts of climate change – particularly heat extremes – on human health and quality of life.

In striving to combat these challenges, researchers and practitioners have increasingly turned their attention to nature-based solutions (NbS). NbS encompass a range of interventions – from urban forestry and green roofs to expansive urban parks – that not only moderate temperatures but also yield

broader ecological, health, and social benefits (Mahmoud et al., 2022; Nesshöver et al., 2017). The International Union for Conservation of Nature (IUCN) and the Government of Canada describe NbS as multifaceted approaches that help communities adapt to climate change while enhancing biodiversity and human well-being (Government of Canada, 2021; IUCN, 2025). Studies have shown that urban greenery as a NbS can mitigate local temperature extremes, reduce energy consumption, and improve air quality (Dardir, Wilson, et al., 2023; Dardir & Berardi, 2021; Y. Wang et al., 2016; Zupancic et al., 2015). Exposure to greenery cover has also shown reduced incidence of physical and mental health conditions in various urban areas, including the GTA (Hystad et al., 2019; Maas et al., 2009; Rotenberg et al., 2022; White et al., 2021). In an urban study of York Region by Dardir and colleagues (2023), the NbS investigated to address the UHI effect was urban greenery cover (GC), including tree cover (TC) and ground vegetation cover (GVC), which demonstrated the potential for GC to dampen UHI effects, lower associated health risks, increase productivity, and lower energy usage. This is consistent with a review study, which identified vegetation (or greenery) cover as the most common factor influencing the UHI effect (Deilami et al., 2018). These studies suggest that GC plays a significant role in urban climate change adaptation while also providing a range of benefits.

A growing body of literature has begun to quantify and value the benefits associated with NbS. For example, Toronto trees and shrubs are estimated to remove 4.60 grams of air pollutants per square metre of GC, which was valued at CAD 792/ha of tree cover (Nowak et al., 2018). Wilson and Xiao (2023) placed an economic value of approximately CAD 133,000 annually on improved health outcomes obtained through increasing GC in the context of implementing an urban park. In York Region, a more comprehensive economic valuation was provided of the benefits associated with mitigating the UHI effect, including lowered emergency department visits, lowered incidence of premature mortality, increased productivity, and decreased energy usage (Dardir, Umberto, et al., 2023). These findings provide empirical evidence that urban GC is not only an environmental amenity but also an economic asset.

Despite the growing evidence on the benefits of urban GC, the systematic economic evaluation of the NbS remains fragmented. Current studies often focus on isolated benefits – such as energy savings or reduced emergency visits – without integrating the full spectrum of direct and indirect advantages. The current state of research highlights an increasing recognition of the need for comprehensive cost-benefit analysis (CBA) frameworks that can capture the environmental and social

benefits as well as the associated costs of such investments. This gap underscores the importance of establishing a robust, integrated methodology to value NbS in urban settings.

1.2 Research Problem

While substantial literature exists on the environmental and social benefits of urban GC, a significant gap persists in the integrated economic valuation of the NbS. Previous research – such as the work by Dardir and colleagues (2023) – has effectively modeled the cooling effects of increased GC scenarios. However, while the modeling of economic benefits included some direct health benefits and indirect benefits (i.e., productivity gains and reduced energy consumption), a holistic treatment of indirect benefits such as biodiversity enhancements or air quality improvements was not provided. The Treasury Board of Canada Secretariat (2019) recommends that both direct and indirect benefits be monetized to facilitate decision-making. However, this existing framework provided only partial assessments. This leads to an underrepresentation of the true economic return on investments into urban greenery cover.

In addition to benefit assessment, the economic costs associated with the installation and maintenance of urban GC have not been rigorously quantified within a single framework – particularly for any Southern Ontario GC study. Many studies have either omitted key cost elements, for example, the opportunity costs of land use (e.g., Panduro et al., 2024), or neglected to include cost considerations in the economic frameworks (e.g., Dardir, Umberto, et al., 2023; J. Wilson & Xiao, 2023). The lack of standardized methods for evaluating both the full range of benefits and the comprehensive costs limits the utility of these studies for urban planners and policymakers.

Another complexity arises from the dynamic nature of urban vegetation. The maturation and non-linear growth of trees mean that environmental benefits such as cooling, carbon sequestration, and air pollutant removal increase disproportionately over time (McPherson, 2002; Nowak et al., 2018). Failure to incorporate such non-linear factors into CBA models results in an incomplete valuation of NbS. This research gap is particularly pronounced for practical applications, where robust data on both benefits and costs is essential for guiding sustainable urban development.

In light of the limitations of previous studies, there is a clear need for an integrated economic framework that simultaneously assesses the benefits and costs of urban GC interventions. Such a model would not only fill an important gap in the academic literature but also provide tangible decision-support tools for municipal authorities striving to implement NbS effectively.

1.3 Statement of Purpose and Research Questions

To address the identified gaps in the systematic economic evaluation of urban NbS, this thesis proposes an integrated economic framework for assessing two urban GC scenarios (moderate and intense) as a climate adaptation strategy in York Region. The research synthesizes the methodologies of prior studies – such as the benefit estimations provided by Dardir and colleagues (2023) and the EcoHealth approaches of Wilson and Xaio (2023) – and extends them by incorporating a more fulsome set of indirect benefits. Furthermore, this framework integrates a dynamic, non-linear growth factor to more accurately capture how benefits evolve as urban GC matures. Costs associated with installation and maintenance over time are also considered in a CBA to assess the economic merit of GC scenarios.

The research questions guiding this study are:

- (1) How do the variations in GC scenarios impact the economic valuation of nature-based urban development in the case study of York Region?
- (2) What are the costs associated with installing and maintaining GC scenarios?
- (3) Do the direct and indirect economic benefits of GC scenarios outweigh the costs of installation and maintenance?

By addressing these questions, the study aims to develop a holistic CBA framework that is both methodologically rigorous and practically applicable. The proposed framework will quantify benefits on an annual basis, projecting them over the expected life span of the GC interventions. Simultaneously, it will estimate all relevant costs, accounting for both immediate expenditures and long-term costs, as outlined in literature and government guidelines (Panduro et al., 2024; Secretariat, 2019).

1.4 Expected Contributions

This research makes a significant contribution by offering a replicable economic model for urban NbS. It provides practitioners and policymakers with a comprehensive tool to evaluate and compare the economic merits of various intensities of GC scenarios in York Region. The incorporation of more factors into a single model, including the novel tree-scaling factor, also advances academic research in evaluating the economic feasibility of NbS. In doing so, it not only advances academic

understanding of NbS valuation but also informs practical urban planning and climate adaptation strategies.

1.5 Thesis Outline

This thesis is made up of five chapters: the introduction, the literature review, the methodology, the results, and lastly, the discussion and conclusion will be presented in the final chapter. The introduction provides an overview of the research problem, proposed research questions, purpose statement, and expected contributions. Chapter two, the literature review, summarizes the current state of knowledge in the research on urban heat island (UHI) effect, the impacts of extreme heat, climate adaptation, and the benefits of GC as an adaptation strategy. Additionally, it focuses on the application of valuation methodologies and cost-benefit analysis to urban GC scenarios and identifies the gap in the literature, forming the basis for this research. The third chapter, methodology, explains research design, data collection, analysis, and interpretation. This chapter also addresses the limitations and strategies to ensure reliability and validity. Chapter four, results, presents empirical findings derived from the data analysis. Chapter five first presents the discussion, which considers findings in the context of the conceptual framework and literature review to address the research questions. Finally, the conclusion provides a synopsis of the thesis, contributions, limitations, and suggestions for future research.

Chapter 2: Literature Review

2.1 Introduction

This chapter critically reviews scholarly and grey literature across several interrelated domains that underpin the economic analysis of urban greenery cover (GC) in York Region as a climate adaptation and UHI mitigation strategy. First, the review establishes context through a discussion of anthropogenic climate change and its urban repercussions, including the UHI effect and its broad impacts on human health and economy. Next, the literature review outlines the role of NbS, particularly in urban settings, and examines the methods used to assign economic value to both the costs and benefits of GC. In doing so, this review identifies gaps that the current thesis seeks to address, such as the need for comprehensive economic valuation frameworks that capture both direct and indirect effects across social, ecological, and economic dimensions.

2.2 Context

2.2.1 Climate Change and Heat

Climate change is described by the Intergovernmental Panel on Climate Change (IPCC) (2014, 2018), as long-term shifts in temperature and weather patterns occurring over extended periods. Long-term research finds unequivocal evidence that human influence, through actions such as fossil fuel combustion, industrialization, and deforestation, is warming the atmosphere, oceans, and land (IPCC, 2021). There is strong support by the scientific community that climate change is already occurring, and that even with significant measures to reduce greenhouse gas (GHG) emissions, some degree of climate change will be inevitable (Coumou & Robinson, 2013; IPCC, 2018, 2021; Lemmen & Kanada, 2004). The sixth assessment report (AR6) by the IPCC states that average global surface temperatures are very likely to increase by 1.0°C to 1.8°C even under very low GHG emission scenarios (IPCC, 2021).

Heat waves, defined as prolonged periods of excessively hot weather, have become more frequent and intense as a result of climate change (Coumou & Robinson, 2013). The increasing global temperatures, primarily driven by human activities such as fossil fuel combustion, industrialization, and deforestation, have exacerbated the occurrence and severity of heat waves worldwide (Coumou & Robinson, 2013). The relationship between heat waves and climate change has been well documented

by climate scientists. According to the IPCC (2021), the frequency and intensity of heat waves have been increasing over the past several decades, and future projections suggest this trend will continue as global temperatures continue to rise.

Even countries commonly considered cold, such as Canada, are highly susceptible to the impacts of hot temperatures. Episodes of extreme heat are increasingly common, and Canadian temperatures are rising two times faster than the global average (Environment and Climate Change Canada, 2022b; Government of Canada, 2019; Y. Wang et al., 2016; Willcott & Cleary, 2022). These episodes can be long-lasting with substantial impacts. A notable example is the summer of 2005 in Southern Ontario. The capital city of Toronto experienced a heat wave spanning 41 days with temperatures above 30 °C, and nights with temperatures of 20 °C or greater (Hengeveld et al., 2005). The number of hot days with temperatures above 30 °C is likely to increase in frequency according to climate modeling scenarios, particularly in British Columbia and the Windsor-Quebec corridor, where York Region is located (Lemmen & Kanada, 2004; Y. Wang et al., 2016). In North York Township, which neighbours York Region, hot days with temperatures exceeding 30 degrees Celsius totalled 25 in the summer of 2024 (May to September), as compared to 7 days in 2014 (Environment and Climate Change Canada, 2025). This increase in hot days highlights the impact of climate change and urbanization in Southern Ontario.

2.2.2 Urban Heat Island Effect

Urban populations are continuing to grow, with more than half of the world's population living in urban areas today, and a projected increase to over two-thirds by 2050 (United Nations, 2018, 2024). Differences in climate in urban settings have been identified in scholarly research from the early 19th century, and this continues to be a problem area under study (Stewart, 2019). These climate differences have been termed “the urban heat island (UHI) effect”, which is a phenomenon where urban areas experience higher temperatures as compared to non-urban (rural) areas surrounding them. Large cities, with populations of one million or more, have been found to be up to 3 degrees Celsius warmer than surrounding areas, and this difference can be up to four times as much during the night (U.S. Environmental Protection Agency, 2008b). The cause of the UHI effect is well studied, and influences include spatial and temporal factors as well as human activities (Deilami et al., 2018; Rizwan et al., 2008; L. Yang et al., 2016). Properties of urban materials influence how solar energy is reflected or absorbed (U.S. Environmental Protection Agency, 2008b). The UHI effect has been

showing an increasing trend in intensity in urban areas. A contributing factor to this trend includes decreasing GC as urban sprawl increases (Levermore et al., 2018; U.S. Environmental Protection Agency, 2008b). Other contributing factors include urban materials, urban geometry, and heat caused by anthropogenic activities (U.S. Environmental Protection Agency, 2008b). As the urban sprawl and percentage of population living in urban areas continue to increase, understanding how UHI impacts cities is crucial for sustainable urban planning to mitigate its effects, especially in the face of climate change (Aghamohammadi, 2022)

2.2.3 UHI and Heat Impacts

Increasing temperatures and UHI trends have already shown social and economic impacts in cities. The urban heat island effect – arising as an outcome of urban development and localized climatic factors – influences air quality, energy demand, water resource integrity, and population health (Aghamohammadi, 2022; U.S. Environmental Protection Agency, 2008b). In Canada, consequences for health and economics in the context of energy consumption and productivity have all been observed (Dardir, Umberto, et al., 2023; Henderson et al., 2022; Y. Wang et al., 2016). Below, more details are discussed regarding these heat-related impacts.

2.2.3.1 Health Impacts

Exposure to extreme heat is known to have immediate as well as long-term health impacts. For example, increased risk of mental health issues, adverse pregnancy and birth outcomes, cardiovascular and respiratory diseases are noted (Ebi et al., 2021). Some populations are particularly vulnerable, such as the elderly, children, and those with pre-existing health conditions, regardless of factors such as income and location (Basagaña et al., 2011; Ebi et al., 2021; Sheffield et al., 2018). In North America, heat-related occupational injuries have increased 33.3% since 2000, making it the most rapidly increasing continent for occupational injuries attributed to excessive heat (United Nations, 2024). Overall, Heat can influence a range a health outcomes and result in increased healthcare needs.

Extreme heat is also associated with increased mortality rates (Ebi et al., 2021; United Nations, 2024). It is estimated that approximately 489,000 heat-related deaths occurred annually between 2000-2019 (United Nations, 2024). This phenomenon is not isolated to one city or country, and in high income countries, heat waves and heat extremes are a major weather-related cause of

death (Ebi et al., 2021). For instance, in 1995, a Chicago heat wave killed hundreds (Klinenberg, 2015). Nearly a decade later, in 2003, Europe saw tens of thousands of deaths that have been attributed to hot summer temperatures, and in 2022, excess deaths from extreme heat exceeded 60,000 (Ballester et al., 2023; European Environment Agency, n.d.). Deaths associated with heat waves, such as the tens of thousands seen in Europe in 2003, are now considered a direct consequence of anthropogenic global warming (Stott et al., 2004). A startling example of heat-related mortality in Canada was the sudden threefold increase in mortality counts in British Columbia resulting from a 2021 heatwave (Henderson et al., 2022). The drastic increases in mortality relating to extreme heat and heat waves emphasize the pressing need to comprehend and respond to the health-related consequences of climate change, while reinforcing the significance of implementing effective heat mitigation measures (Dardir, Umberto, et al., 2023).

2.2.3.2 Economic Impacts

Economic impacts of climate change are already being observed and projected to drastically increase in the coming decades (United Nations, 2024; Willcott & Cleary, 2022). It is estimated that the combined effects of extreme heat cost the United States over \$162 billion in 2024, or equivalent to nearly 1% of the US Gross Domestic Product (GDP) (Burton & Wickerson, 2025). In Canada, the physical costs of climate change are projected to cost \$2.772 trillion under the 2°C warming scenario, and upwards of \$5 trillion in a 5°C warming scenario, in capital output lost between 2015-2100 (Willcott & Cleary, 2022). The Canadian Climate Institute estimates that Canadian GDP could fall by 12 percent and household incomes by 18 percent in a high-emission scenario, as compared to a stable climate scenario (Canadian Climate Institute, 2022). Other measurements of economic impacts connected with heat and climate change include health care costs, productivity loss, and increased energy usage.

Firstly, there is a substantial economic cost associated with the health impacts linked to heat stress. For example, general increases in morbidity and emergency department visits are associated with heat stress and hot ambient conditions, and this is projected to increase with expected higher temperatures and increased occurrence of heat waves due to climate change (Ebi et al., 2021). The estimated average costs of an emergency department visit in Ontario for 2020 were CAD \$226, according to the Canadian Institute for Health Information (CIHI) (CIHI, 2022a; Dardir, Umberto, et al., 2023). Therefore, with increasing emergency department visits projected from heat stress, there is

an associated increase in healthcare costs. Additionally, increasing heat leads to increased levels of ground-level ozone – a factor contributing to smog – which is associated with respiratory illnesses. This is associated with increased healthcare costs, as well as projected costs of death and lost quality of life estimated at \$86 billion annually by 2050 (Canadian Institute for Climate Choices, 2021). Further healthcare costs are associated with the increasing prevalence of Lyme disease and mental illness as heat increases (Canadian Institute for Climate Choices, 2021). In a high emissions scenario, increased incidence of Lyme disease alone is expected to increase healthcare costs by CAD \$270 million annually (Canadian Climate Institute, 2022). Altogether, it is estimated that healthcare costs may increase by up to CAD \$400 million annually due to heat-related illness increases (Canadian Climate Institute, 2022). Increasing heat has a range of negative impacts on human health, all of which are projected to increase strain and cost on the healthcare system.

Secondly, it is well established that increased heat is shown to have a substantial impact on productivity with associated economic losses. Losses in labour capacity due to heat exposure were reported by the United Nations (2024) at USD\$863 billion (2022). Several research studies across the globe have also reported on productivity losses due to increasing temperatures and heat exposure. Countries including China, Malaysia, and Australia have all reported evidence of productivity loss associated with heat stress and temperature increases in recent years (Venugopal et al., 2022; Xia et al., 2018; Zander et al., 2015; Zander & Mathew, 2019). Increasing heat is also impacting productivity in North American economies. For example, a study in the US found that hot summers slowed economic growth by 0.15 to 0.25 percentage points with every degree Fahrenheit of temperature increase above the state's average summer temperature (Colacito et al., 2019). The same study also predicted that increasing seasonal temperatures could result in reduced economic growth by up to one-third over the next century in the US (Colacito et al., 2019). Similarly, increasing temperatures are impacting workers and productivity in Canada (Peters et al., 2015; Vanos et al., 2019). A longitudinal study of outdoor workers in Ontario, Canada demonstrated that an average of 22 hours per labourer were lost each summer due to heat, which amounted to an average loss of CAD\$1100 (2019) or a combined loss of approximately CAD\$220,000 (2019) for 200 workers not inclusive of corporation losses due to reduced output (Vanos et al., 2019). In 2021, CIHI used modeling to estimate that under a high-emissions scenario, climate change may result in 128 million work hours lost each year by 2100, equivalent to 62,000 full-time workers. This is projected to cost nearly CAD \$15 billion (Canadian Institute for Climate Choices, 2021). Altogether, there is

compelling evidence that increasing temperatures are, and will continue to, impact productivity and the economy both in Canada and globally.

In addition to costs for increasing healthcare needs and losses in productivity, economic impacts can result from increased energy consumption due to extreme temperatures. As temperatures rise, cooling needs increase, straining the energy infrastructure and creating vulnerabilities to businesses, critical services, and households (United Nations, 2024). Cooling currently accounts for approximately 20 percent of global electricity consumption, which is expected to increase based on current policies (United Nations, 2024). Further amplifying this demand, the UHI effect and extreme heat decrease the efficiency of cooling devices, such as air conditioners (AC), requiring even more energy (Miner et al., 2017). Increased demand leads to increased cost. For example, in Ottawa, Canada, a mean UHI of 0.8 degrees Celsius resulted in an annual excess cost of USD \$6.1 million (2017) for AC operation. This does not account for costs associated with possible infrastructure damage due to the burden, or increased maintenance costs of equipment due to increased usage (Miner et al., 2017). At a national level, it has been estimated that a high emission scenario would result in an increased cooling demand, leading to 4% annual increase in electricity usage. This increase is estimated to cost approximately CAD \$5.3 billion annually in operating expenditures and electrical system capital alone (Canadian Climate Institute, 2022). In summary, cooling is a large energy demand, with cost increases due to even small increases in temperatures associated with climate change and UHI effects.

Studies show that there are links to economic losses due to increasing heat and the UHI effect. This can result from decreasing productivity, increasing healthcare costs, and increased energy usage as temperatures rise. While there are many other costs associated with and attributed to climate change, these are specifically focused on the increase in temperature arising from anthropogenic climate change and the UHI effect. Together, the research on economic impacts supports a need for UHI mitigation and climate adaptation measures to reduce economic burden now and in the coming years.

2.3 Climate Adaptation

Temperatures are rising in Canada, and city temperatures are intensifying. With concentrated populations, impacts are magnified, making the need for adaptation in Canada imperative (Environment and Climate Change Canada, 2022b; United Nations, 2024). Environment and Climate

Change Canada has defined adaptation as “adjusting our decisions, behaviours and activities to account for existing or expected changes in climate” (Environment and Climate Change Canada, 2022a). One example to help adapt and build resilience is to protect the health of Canadians during heat events by making changes (Environment and Climate Change Canada, 2022a). As part of Canada’s National Adaptation Strategy, building resilience requires action in five areas: reducing climate-related impacts, improving health and well-being, protecting and restoring nature and biodiversity, building and maintaining resilient infrastructure, and supporting the economy and workers (Environment and Climate Change Canada, 2024). The economic case for adaptation is strong. It is estimated that for every \$1 invested in proactive adaptation today, \$13 to \$15 will be returned in direct and indirect benefits in the coming years (Canadian Climate Institute, 2022). Below, NbS will be discussed as a climate adaptation measure, specifically to address heat, and the state of knowledge on associated benefits will be investigated.

2.3.1 NbS as Climate Adaptation and Mitigation Strategies

Nature-based solutions are an umbrella concept that links both social and ecological aspects. As defined by the Government of Canada and the International Union for the Conservation of Nature (IUCN), Nature-based Solutions (NbS) are actions that are used to adapt to climate challenges, while also providing benefits for biodiversity and human well-being (Government of Canada, 2021; IUCN, 2025). NbS is a relatively new term in environmental management and research, and it has connections to other established concepts for understanding and managing ecosystems (Nesshöver et al., 2017). The exact positioning and relation of NbS to other commonly used terminology and concepts is still being explored and discussed by researchers (Mahmoud et al., 2022; Nesshöver et al., 2017). For example, NbS can overlap and relate to several terms, including but not limited to green infrastructure, blue-green infrastructure, ecosystem services, ecosystem-based disaster risk reduction, and ecosystem-based adaptation or mitigation (Nesshöver et al., 2017; Panduro et al., 2024). For instance, both green infrastructure and NbS aim to provide ecological and social benefits through natural solutions, and in some cases, the two may be seen as synonymous. However, there are some differences, specifically in the wording of “solutions” versus “infrastructure” – where NbS are used as a “solution” for adapting to climate change, green “infrastructure” may also provide this, but can be used in other contexts (Nesshöver et al., 2017). Green infrastructure is land-based and includes solutions such as urban parks, urban forestry, green roofs, living walls, and other nature-based terrestrial areas (Nesshöver et al., 2017).

GC can be used as a NbS, adapting to climate change and mitigating challenges like the UHI effect (Fu et al., 2022; Hayes et al., 2022; Wong et al., 2021). With a focus on mitigating the UHI effect and adapting to temperature increases and extreme heat events associated with climate change, academic research has established direct benefits related to cooling. For example, GVC and TC have been shown to reduce peak surface temperatures in cities by 2 to 9 degrees Celsius, with variation depending on scale and design (Wong et al., 2021). In a study of York Region, Ontario, modeling of increased GC showed that humidex values could be decreased from 40.6 to 34.1 during a typical summer season by applying an intense coverage scenario, reducing the scale of comfort from “great discomfort” to “some discomfort” and avoiding heat warning conditions (Dardir, Umberto, et al., 2023). Similarly, heat reductions associated with GC have been observed in US cities. For example, suburban areas with mature trees were found to be 2 to 3 degrees Celsius cooler compared to new suburban areas without trees, and grass sports fields 1-2 degrees Celsius cooler than surrounding areas (Huang et al., 1990; Kurn et al., 1994; U.S. Environmental Protection Agency, 2008a). Through shading and evapotranspiration, GC can help to reduce peak temperatures and mitigate the UHI effect (U.S. Environmental Protection Agency, 2008a).

Utilizing GC as a strategy to reduce temperatures also brings a range of other benefits. As identified by the US Environmental Protection Agency, the use of trees and vegetation for mitigating UHI effect is also associated with the benefits of reduced stormwater runoff, energy usage, greenhouse gas emission, air pollution, exposure to ultraviolet (UV) rays, as well as increased quality-of-life benefits including lowered urban noise, increased property values, reduced crime, and other social benefits (U.S. Environmental Protection Agency, 2008a). A review study by the National Research Council of Canada echoed this, with identified direct benefits of GC as a NbS, including decreased cooling loads, reduced mortality, and improved urban climate and air quality (Hayes et al., 2022). A range of indirect benefits are also identified, including but not limited to carbon sequestration, water purification, biodiversity, mental well-being, and job creation (Hayes et al., 2022). In the study of York Region, direct benefits linked to the improved thermal comfort provided by increasing GC, such as reduced healthcare costs and reduced mortality, were valued in an economic framework. The study also quantified some indirect benefits, such as the economic benefits associated with reduced energy consumption and productivity (Dardir, Umberto, et al., 2023). However, the study did not consider a full range of indirect or co-benefits provided by the NbS of GC. To consider the increased GC scenarios as a NbS, it is important to consider the range of benefits

provided, including benefits for biodiversity and human well-being, in addition to the known benefits of heat reduction and improved thermal comfort.

Aside from the known benefit of decreasing urban temperatures and improving thermal comfort provided by increasing GC in urban areas (Dardir, Umberto, et al., 2023; Dardir & Berardi, 2021; Fu et al., 2022; Wong et al., 2021), there are two major indirect environmental and ecological benefits that this research will investigate, namely biodiversity and air quality. Next, benefits for human well-being will be discussed, followed by an examination of resultant economic benefits. Together, the implementation of urban GC and these associated benefits align with important action areas in Canada's National Adaptation Strategy and the definition of a NbS for adaptation (Environment and Climate Change Canada, 2024; Government of Canada, 2021; IUCN, 2025).

2.3.1.1 Environmental and Ecological Benefits of GC

Increasing urban green spaces and natural areas can help to increase biodiversity despite the impacts of increased urbanization and climate change. Canada has more than a thousand species of pollinating insects, including bees, which perform over 70% of pollinating services in North America (Seeds of Diversity, 2024). Globally, approximately 20% of food crops require pollinators to produce food, with many more crop types showing improved product size and yield with pollination services (Klein et al., 2006). An example of this is the requirement for both wild and honeybee pollination services to produce fully developed strawberries, in contrast to misshapen fruits on plants only serviced by one pollinator species (Chagnon et al., 1993). Several studies in Ontario have been conducted to investigate the impact of land type on pollinator abundance and diversity. One such study, conducted in four Ontario cities, found that naturalized areas of at least 50 square metres, regardless of land use zoning type (e.g., industrial vs. greenspace), increased bee diversity and abundance (Horn, 2011). Another recent study in the city of Ottawa provides insight by finding a negative correlation between impervious surface types and bee species richness and abundance (Gerner, 2020). Further Canadian study in the city of Toronto linked increased bee abundance with decreased urbanization intensity, measured by the percentage of impervious surface area surrounding the sampling plots (Brasil et al., 2023). These findings suggest that even small GC implementations, modifying the surface type of the urban area, can help to increase pollinator abundance and biodiversity.

NbS can also aid in adaptation and mitigation, helping to improve air quality. Buildings are responsible for approximately 28% of global energy-related GHG emissions, with this figure rising

drastically in densely populated urban areas. The UHI effect further exacerbates this issue by increasing demand for cooling (Hayes et al., 2022). Canadian municipalities are increasingly adopting NbS as integrated strategies for climate mitigation and adaptation. One of the core categories of NbS is urban GC, which assists in lowering building energy demand and the associated carbon emissions by improving the local microclimate. Additionally, GC contributes to carbon sequestration, further supporting emission reduction goals, improving air quality, and long-term climate resilience (Hayes et al., 2022; Konijnendijk et al., 2013). Numerous studies have also identified that urban GC, such as parks, can help to reduce other air pollutants and improve air quality (Konijnendijk et al., 2013; Nowak et al., 2006, 2018; Zhou, 2017). A computer simulation model utilizing local data from 86 Canadian cities estimates that urban trees removed 16,500 tonnes of air pollutants in 2010, including CO, NO₂, O₃, PM_{2.5}, and SO₂ (Nowak et al., 2018). This reduction in air pollutants shows benefits in avoided illnesses and strain on the healthcare system (Nowak et al., 2018). GC as a NbS has also been associated with improved air quality in field studies throughout Southern Ontario. A study by Anderson and Gough (2020) found a correlation between reduced ozone, nitrogen dioxide, and carbon dioxide associated with the presence of green infrastructure in urban areas. Urban GC can not only reduce health risks through air pollutant removal, but it can also aid in carbon sequestration and reduce temperatures, leading to lowered GHG emissions. Together, these factors aid in both adaptation and mitigation of the UHI effect.

2.3.1.2 Benefits for Human Well-Being

Urban GC shows a range of benefits for human well-being, including physical health, mental well-being, and decreased mortality rates. In a systematic review study, a consistent negative correlation between exposure to urban greenspace and mortality, heart rate, and violence was found.

Furthermore, consistent positive correlation was found between urban greenspace exposure and attention, mood, and physical activity (Kondo et al., 2018). The reduction in air pollutants associated with increased GC is also connected with a range of reduced health risks, including acute respiratory symptoms, asthma, bronchitis, cardiovascular disease, and mortality (Nowak et al., 2018).

Additionally, there is evidence suggesting that proximity and access to urban GC have a positive impact on mental well-being. In a large CARTaGENE cohort study of Quebec, it was found that even a 0.1 increase in greenspace within 500 metres of a participant's residence resulted in reduced incidence of depression and anxiety (Hystad et al., 2019). Similarly, Wood and colleagues (2017) found that access to neighbourhood greenspaces increased general mental wellbeing, and a study in

Toronto, Ontario found that a lack of GC can influence prevalence of schizophrenia – showing that residents of neighbourhoods with low levels of greenspace had increased risk of developing schizophrenia by 24%, after controlling for age and socio-economic factors (Rotenberg et al., 2022). Together, these studies suggest that increasing GC has a positive correlation with human well-being, both physical and mental, while also reducing mortality.

2.3.1.3 Economic Benefits of GC

The direct and indirect benefits of increasing GC have a range of potential economic benefits. For example, lowered GDP losses, decreased energy consumption costs, decreased loss of productivity, and reduced healthcare expenditures. It is estimated that proactive investment in adaptation can cut projected GDP change by 47% to 53% in low and high emission scenarios, respectively (Canadian Climate Institute, 2022). While adaptation with GC is only one form of adaptation, it will assist in lowering temperatures and mitigating the UHI, which will in turn reduce losses from heat labour productivity, premature death, electricity demand change, and heat-related illness (Canadian Climate Institute, 2022). Increased shading alone can reduce temperatures and lower expected productivity losses by 12% (Canadian Climate Institute, 2022). Modelling simulations of increased GC scenarios in York Region support this by showing that increased GC will reduce temperatures and heat stress, thereby avoiding costs associated with lost productivity, energy usage, emergency department visits, and premature mortality (Dardir, Umberto, et al., 2023). Not only can GDP losses be avoided through cooling provided by GC, but increases in GDP can be realized through job creation required for installation and maintenance activities (Government of Canada, 2021; Green Analytics, 2019; Hayes et al., 2022). For example, the 50 Million Tree Program in Ontario is estimated to provide an annual equivalent of 103.8 full-time jobs and over \$12.6 million (2019) in Canadian GDP (Green Analytics, 2019). While there is evidence of benefits, there is no direct market value to many of these benefits, leading to further challenges in quantifying a dollar value associated with benefits.

2.4 Economic Valuation of Costs and Benefits of GC

Placing value on environmental costs and benefits, and ecosystem services (ES), is still a struggle today, even though it has been understood for several decades that environmental quality matters (Kula, 1994). Placing value on environmental factors is important for several reasons. First, economic valuation plays a crucial role in highlighting that environmental resources are not limitless nor freely available, even in the absence of formal market structures. By assigning value to environmental

inputs, especially when faced with developmental pressures, such valuation may reveal their increasing scarcity (Kula, 1994). Valuing environmental resources also facilitates more equitable decision-making by allowing development projects to be assessed from a broader, more informed perspective. In the context of environmental restoration, economic valuation helps to quantify the benefits of proposed interventions, providing clarity on their worth (Kula, 1994). Moreover, valuation of environmental factors reduces subjectivity in cost-benefit analysis by bridging the gap between quantifiable and non-quantifiable impacts, which is particularly important given the historical tendency to omit environmental considerations due to their presumed intangibility. Lastly, valuation ensures a more accurate representation of economic performance at regional and national levels and supports effective policymaking (Kula, 1994). Although there is an established need for economic valuation of costs and benefits associated with environmental factors, methodologies and frameworks are still being developed.

There is also a pressing need for innovative funding models to underscore the importance of urban GC, with municipal budgets often under strain (García De Jalón et al., 2020). Addressing this need, van Zoest and Hopman (2014) developed a tool to incorporate the economic advantages of GC into municipal financial systems, inspired by the TEEB study. Similarly, Harnik (2009) introduced a framework to assess urban park benefits, highlighting seven main factors to be quantified: increased property values, tourism, direct use, improved health, stronger community cohesion, cleaner water, and cleaner air. In Canada, Wilson and Xiao (2023) utilized the EcoHealth framework to value the resulting economic returns of health benefits associated with an urban park project. This framework is also applicable to urban green spaces as developed under the leadership of the EcoHealth Ontario (EHO) research group and Green Analytics (J. Wilson & Xiao, 2023). Despite the growing knowledge on the economic value of urban GC as a NbS, there is no known standardized framework or funding model to incorporate the large range of economic advantages from various types of NbS into the Canadian municipal financial systems.

To quantify the associated urban GC benefits and assign value to non-market goods, different methodologies may be applied. These include market and non-market valuation methods, which can be used to assign value to ecosystem services (ES). Table 1 outlines methodologies that are commonly used in the valuation of green spaces, how data is obtained, the strengths and weaknesses of the methodologies, and their relevant applications. For example, a Contingent Valuation Method (CVM) may be used to evaluate environmental assets by assessing people's willingness to pay or

assessing what they would expect to receive in compensation in order to accommodate the proposed cost of an environmental project (Pearce & Turner, 1989). Two examples of this involve assessment of reclaimed wastewater for use in agriculture and recreational urban parks (Alcon et al., 2010; Verlicchi et al., 2012). CVM was also utilized by researchers in the valuation of a project to convert an old train station to an urban park area. The contingent valuation showed that people living closer to the proposed park were more willing to pay due to its accessibility (del Saz Salazar & Menendez, 2007). While the CVM and other methods have strengths and relevant applications, there are limitations to their application, including time to collect data and survey limitations.

Table 1: Economic Valuation Methodologies Used in Greenspace Valuation

(Adapted from: Green Analytics, 2020, p. 12)

	Data	Strengths	Limitations	Relevant Applications
Market Valuation Methods	Available through health information databases and public accounts	Integrates well into government decision-making frameworks and budgetary processes	Partial reflection of monetary value (only considers use value)	Health system savings, avoided burden of illness
Contingent Valuation	Survey	Flexibility to evaluate future scenarios (planning and policy)	Measures stated behaviour (not measured behaviour) Vulnerable to survey design and other survey limitations	Determine Willingness to Pay (WTP) to reduce the risk of illness Evaluate hypothetical planning and policy scenarios

	Data	Strengths	Limitations	Relevant Applications
Hedonic Pricing	Available through property sales and tax assessment data	Useful in valuation of individual parks or green spaces	Difficult to control other factors that influence property values Not applicable to specific health outcomes Difficult to link to specific green space functions	Determine the total economic value of a greenspace
Travel Cost Method	Survey or service use data	Provides means to determine WTP to access a service of benefit Useful to estimate the overall use value or recreational benefit	Restricted in the ability to link to direct health benefits	Estimate direct use value
Benefit Transfer Method	Prior studies	Estimate economic value in the absence of resources/data	Depends on the quality of primary studies and contextual relevance	When applied to a study area of a similar context and socio-economic conditions

	Data	Strengths	Limitations	Relevant Applications
Subjective Wellbeing	Survey and health expenditure data	Well-being-based approaches are increasingly seen as important information for decision-makers	High-level statistical analysis required, and difficulty determining if well-being gain is due entirely to greenspace use/exposure	Determine changes in well-being and corresponding health system savings

Two methods employ data from other sources to monetize benefits and costs. First, the benefit transfer method can be utilized in the valuation of urban GC, inclusive of parks, green spaces, trees, swales, and other GC. This method employs results of previous valuation studies in similar contexts and estimates the value of similar GC in a new project/area. This is a commonly accepted method utilized in both academic research and in government assessments, as it allows for the swift quantification of values (Green Analytics, 2020; Secretariat, 2019). Similar to the benefit transfer method, another method commonly used values costs avoided, replacement costs, and or substitute costs. This is known as the direct cost-savings approach, and is a well-known and authenticated method (Moslehi et al., 2020; Xie et al., 2023). For example, Dardir and colleagues (2023) valued a proposed GC scenario by including assigned monetary values to avoided healthcare costs and avoided costs of energy use. Similarly, Wilson and Xiao (2023) used this method to value avoided costs of healthcare associated with health changes connected to park implementation. Utilizing public accounts and health information databases allows for market valuation of the avoided costs, which integrates well with government budget processes and decision-making frameworks (Green Analytics, 2020). These studies collectively demonstrate assigning monetary value to the benefits of urban GC in an economic context using secondary data.

Determining the economic costs of urban green spaces requires consideration of multiple factors. Costs of GC scenarios can include installation, maintenance, and opportunity costs. Some installation costs include, but are not limited to, components such as plantation of the greenery (trees

and other plants), soil preparation, removal of pavement, as well as the cost of the trees and plants themselves. Maintenance costs of GC areas can include costs of labour and supplies, and opportunity costs can include factors such as land opportunity costs and potential lost revenue from other project opportunities (Panduro et al., 2024; Privitera & Ma, 2022). To complete cost assessment, some of the same methodologies can be utilized, such as market valuation and the value transfer method used by Panduro and colleagues (2024) in the cost assessment of multiple urban NbS. However, there are limitations. For example, greenspaces and tree cover installation costs can vary greatly depending on various factors, including location, soil treatment, landscaping, preparation, planting, species selection, and the addition of amenities such as benches and gravel pathways (Panduro et al., 2024; Privitera & Ma, 2022). The size of the project can also affect costs, with economies of scale playing a role. Additionally, the extent and complexity of facilities influence the expense, as do labour-intensive tasks. Consequently, regions with lower labour costs may have an advantage over those with higher labour costs when it comes to the overall costs of developing NbS (Panduro et al., 2024). As labour is also required in maintenance, this should also be considered in maintenance costs. Therefore, project context, socio-economic similarity, and economy of scale should be considered in transfer methods for the cost of NbSs.

In the case of economic valuation of urban NbS, a systems-thinking approach should be used. As NbS are complex systems, within larger urban and ecological systems, we must consider the complex challenges of valuation of benefits beyond short-term economic gains and include non-material and co-benefits (Mahmoud et al., 2022). In previous studies investigating the value of benefits provided by urban green spaces, isolated components or benefits of the system were focused on or valued. In a Canadian Context, researchers estimated the value of social benefits provided by TC in 86 Canadian cities using a methodology that considered the cost of illness, willingness to pay to avoid illness, reduced productivity due to health impacts, and value of life (Nowak et al., 2018). Similarly, in southern Ontario, two recent studies in the GTA focused on specific benefits and neglected to take a holistic approach. In York Region, Dardir and colleagues (2023) focused on the solution of UHI mitigation only, and the associated direct and indirect benefits of productivity, energy usage, and health (by way of decreased emergency department visits and mortalities). In the 2023 study of a park implementation in Peterborough, Ontario, researchers focused on the social benefits and valued the associated physical and mental health outcomes using a novel valuation framework (J. Wilson & Xiao, 2023). Neither study included a systems approach to valuation of impacts and co-

benefits, nor did they include any valuation of ecological benefits (e.g., biodiversity). Using a holistic approach to evaluating benefits provides a more accurate estimation of the value of a NbS, and including cost estimates provides practitioners information required to evaluate investment and policy decisions.

2.5 Cost-Benefit Analysis

Cost-benefit analysis (CBA) is a well-established economic method used to support decision-making by quantitatively comparing the benefits and costs of a specific investment (Brouwer & Pearce, 2005; Hanley & Spash, 1996; Hutton et al., 2006; Kula, 1994; Pearce & Turner, 1989; Young, 2005). CBA originated in 1844, developed by Jules Dupuit (Kula, 1994). The theory of CBA developed by Dupuit does not impose limitations on the costs and benefits that should be included. In fact, all forms of costs and benefits – monetary and non-monetary, including unpaid values – should be evaluated prior to initiating public infrastructure projects according to this theory (Kula, 1994). CBA is a technique still used today to determine whether projects are in the interest of the public by assigning monetary value to each input and output of a project. Generally, it can be used to determine whether or not to implement a project or policy (Hsu & Chao, 2020; Liu et al., 2010; Secretariat, 2018, 2019). Benefit and cost values are compared; a project is generally deemed worthwhile to implement if benefit values are greater than cost values, or the net present value (NPV) is greater than 1 (Verlicchi et al., 2012). There are multiple types of CBA. Financial CBA is limited to the market value of costs and benefits. However, economic CBA is inclusive of both market value and societal perspective values on costs and benefits (García De Jalón et al., 2020). Additionally, there is a social CBA. This type of economic assessment is used in a wide range of scenarios, including in decision-making and the assessment of the economic value of NbSs (García De Jalón et al., 2020).

An important factor in CBA and the determination of NPV is the use of discounting. Rationale for discounting is commonly based on investment and consumption (Arrow & Kruz, 2013; Lind et al., 2013). On the basis of consumption, it is rationalized that due to rising consumption, future generations are expected to be wealthier than today's generation, and diminishing marginal utility from consumption results in the need to discount future consumption (Costanza et al., 2021). The other rationale for discounting is that, due to an assumed positive return on investment, money invested now is worth more than money invested in the future. Therefore, future investments should be discounted (Costanza et al., 2021). Similarly, Canadian CBA guidelines recognize this rationale in

their justification for discounting by stating that benefits and costs require discounting to account for time value and time preference of money – in other words, benefits are preferred now and payments later (Secretariat, 2019). While the national discount rates are recognized at 7% (real rate) and 3% (social rate), there is a great deal of variation in discount rates and approaches used (Costanza et al., 2021; Secretariat, 2019). For example, the standard approach to NPV calculation is a constant discount rate, which does not change over time or circumstance. However, hyperbolic, decreasing, intergenerational, and pluralistic discount rates are among some of the other approaches (Costanza et al., 2021). For example, hyperbolic discounting argues that discount rates should decline with time to account for uncertainty. Alternatively, Costanza suggests that different discount rates be used for different goods/services provided by different capital types (i.e., natural, social, human, or built capital) (Costanza et al., 2021). Overall, there is a large variation in discount rates used, and in the approach applied to discounting – all of which are still investigated and debated among economists.

Canadian regulations for CBA of federal regulations state that direct benefits and costs are those that are directly attributed to the planned outcome of the project or regulation (Secretariat, 2019). In the case of this study, direct benefits would be those attributed to heat mitigation. Additionally, the Secretariat guidelines for CBA also recognizes that other costs and benefits not directly related to the intended outcome of the project or regulation (indirect costs and benefits) should be accounted for, when possible, to provide decision makers with as much information as possible. However, it can be more challenging to quantify and monetize indirect benefits and costs, and this should be considered on a case-by-case basis, given the accessibility to data (Secretariat, 2019).

2.5.1 CBA in GC Valuation

CBA is a useful tool in planning and decision-making when it comes to NbSs such as GC. However, in previous years, environmental consequences and ES were often not included in CBA calculations on the basis that they were essentially unquantifiable (Kula, 1994). With progress in valuation methods for environmental, ecological, and social consequences, there is the capacity to include a wider range of direct and indirect benefits in a CBA of nature-based solutions. The effectiveness (benefits provided) and cost-effectiveness (analysis comparing relative costs and outcomes) of GC are integral to its implementation planning as a NbS in various urban areas. For example, cost-effectiveness is included in the European Commission's definition of NbS, as it states that NbS are:

“Solutions that are inspired and supported by nature, which are cost-effective, simultaneously provide environmental, social, and economic benefits, and help build resilience.” (European Commission, 2024). Embedding the requirement for them to be cost-effective in the definition of what a NbS is, the European Commission helps to build the case for providing a CBA of NbS.

Research has identified a range of CBA results for different NbS. For example, a study by the US Forest Service conducted a CBA of street tree planting in Wabena Falls over a 40-year period. Benefits included were energy savings, air pollution removal, hydrology, and esthetics (McPherson et al., 2006). Through assessing different tree sizes in a CBA, it was found that costs and benefits varied greatly with tree size; however, NPV was positive for all tree sizes, and benefit-cost ratio ranged from 1.62 to 3.52 (McPherson et al., 2006). While this CBA did return positive net benefits, it did not include discounting in the calculations. In another CBA study by McPherson (2007), the influence of the discount rate and costs were examined. In a single tree example over a 40-year period, the value returned was positive using a benefit-based approach which did not consider the costs of planting and management. However, in a multi-tree example, the NPV returned over a 15-year period was negative with discount rates from 0% to 10% due to repair costs of sidewalks (McPherson, 2007). These results showed that large costs can outweigh benefits even when discounting is adjusted. In another CBA study, the focus was on green infrastructure in the LiuChuan River corridor with direct benefits relating to water, electricity, and carbon taxes. Even with a total annual benefit of \$1.14 million, it was found that the net present value was negative when a 3.5% discount rate was included over a four-decade period (Hsu & Chao, 2020). Both studies included different benefits, and another notable difference is the omission of opportunity costs from the 2006 study by the US Forest Service. The omission of cost categories, varying discount factors, along with differences in benefit scope could account for a difference in results.

In the literature, there are many shortcomings in the CBA of NbS. Although it is a widely used tool to assess the feasibility of projects and help to inform decision makers, it is a complex process. One reason for this is the difficulty in assessing the full range of benefits. Many CBAs of urban NbS focus on direct benefits associated with the solution in question (e.g., flood cost savings from flood mitigation solutions) rather than including indirect or co-benefits (such as biodiversity or health benefits) (Chelli et al., 2025). This can provide an incomplete assessment of costs and benefits. Furthermore, methodological choices and assumptions must be made in how to assess costs and benefits. For example, factors such as discount rate and temporal factors can greatly influence

outcomes and are varied in previous studies. A literature review study of CBA in urban NbS has identified a wide range of discount rate variation and even omission, and that temporal factors are often not included in the analysis (Chelli et al., 2025). This can lead to variation in results and misleading assessments. For example, some ES benefits – such as recreational or mental health benefits – may be realized immediately, while others may change over time (e.g., carbon sequestration) (Chelli et al., 2025; U.S. Environmental Protection Agency, 2008a). Multiple studies have recognized that benefits such as cooling and air pollutant scale non-linearly with tree canopy coverage growth (Nowak et al., 2018; Schwarz et al., 2015; Y. Yin et al., 2024). Yet, this is often not included in the CBAs of urban GC. One known example that did include a canopy scaling factor dates back to 2007, by a well-known researcher in urban forestry (McPherson, 2007). No known examples have been found in the Canadian CBA of urban GC to include temporal scaling of benefits and holistic direct and indirect benefit inclusion. Overall, including a more holistic approach to the inclusion of costs and benefits, critically assessing valuation methods, and considering factors such as temporal scaling are all ways in which CBA can be strengthened as a tool in assessing the feasibility of NbS.

From a decision-making standpoint, similar principles apply to the assessment of cost-effectiveness when considering planning and policy across North America. For example, in 1936 the US Congress passed an act introducing an approach that prioritized projects, “[...] if the benefits to whomever they may accrue are in excess of estimated costs [...]” (U.S. Supreme Court, 1941, p. 313). This cost-benefit approach to project assessment in the US is still utilized, and costs of projects and regulatory processes must be considered in addition to potential benefits (Harvard Law Review, 2015). Similarly, Canada has a policy on cost-benefit analysis outlining mandatory requirements for analysis of proposed federal regulations (Secretariat, 2018). These acts and policies can be applied to GC planning in some circumstances. However, there are no known policies requiring CBA at a municipal level for GC scenarios or NbS project proposals despite the usefulness of this approach for informing decision makers.

2.6 Summary

Academic literature and government policy have identified Cost-Benefit Analysis (CBA) as a priority knowledge need for implementing nature-based solutions (Grace et al., 2021; Secretariat, 2019; U.S. Supreme Court, 1941). It has also been established through the literature review that the benefit

analysis of NbS is limited in scope, and cost analysis is lacking, particularly when it comes to the York Region. Furthermore, it is understood that tree canopy growth impacts both microclimate as well as potential benefit realization (Nowak et al., 2018; Schwarz et al., 2015; Y. Yin et al., 2024). However, literature review has shown that this factor is often not included in modelling or benefit calculations (Chelli et al., 2025). To address these gaps, this study aims to provide a more comprehensive framework for economic assessment of costs and benefits associated with GC as an urban NbS for heat mitigation in the case study of York Region.

Chapter 3: Research Methods

3.1 Introduction

To address research gaps, this study aims to answer the following research questions:

(1) How do the variations in GC scenarios impact the economic valuation of nature-based urban development in the case study of York Region? (2) What are the costs associated with installing and maintaining GC scenarios? (3) Do the direct and indirect economic benefits of GC scenarios outweigh the costs of installation and maintenance?

Answering the research questions of this thesis, three phases were used. First, the benefits of two GC scenarios in York Region were calculated and compared. Next, costs associated with both GC scenarios were calculated in order to answer the second research question. Finally, a CBA of both scenarios was conducted to answer the third research question. This research methods chapter describes the quantitative framework used to evaluate urban GC as a climate adaptation and UHI mitigation strategy for York Region. The approach used a comprehensive cost-benefit analysis (CBA) that first quantified individual benefit and cost components for different GC scenarios and then integrated these estimates using standard economic metrics. The method builds on validated simulation models from Dardir and colleagues (2023) and recent advances in economic frameworks assessing NbSs (Chelli et al., 2025; Dardir, Umberto, et al., 2023; J. Wilson & Xiao, 2023). A key innovation is the explicit incorporation of non-linear tree canopy growth over time into the benefit calculations.

This chapter contains seven sections. First, a brief description of the case study region is provided in section 3.2, and a description of the proposed GC scenarios is provided in section 3.3. Next, the research design and approach section discusses the research design used to complete the analysis. Section 3.5 contains the data collection details, followed by section 3.6 outlining the data analysis that explains methods used for analysis of benefits, costs, and finally CBA. Next section 3.7 briefly discusses reliability and validity, and finally, section 3.8 outlines research limitations.

3.2 Study Region

York Region is located in Southern Ontario, just north of the city of Toronto (see Figure 1). The region contains nine municipalities. Known as part of the GTA and Greater Toronto and Hamilton

Area (GTHA), it is the fourth fastest growing region in the GTHA (York Region, 2022). In a Canadian context, York Region is the seventh largest Census Division, and it is the third largest in Ontario. The region is also home to the fastest-growing municipality in all of Canada, East Gwillimbury (York Region, 2022). Despite the region's greening strategy, York Region municipalities are among the 94% of medium and large population centres that have shown declines in green spaces over the last 20 years. For example, the town of Stouffville within York Region has seen a decline in urban greenness of nearly 10% (Office of the Auditor General of Ontario, 2022).

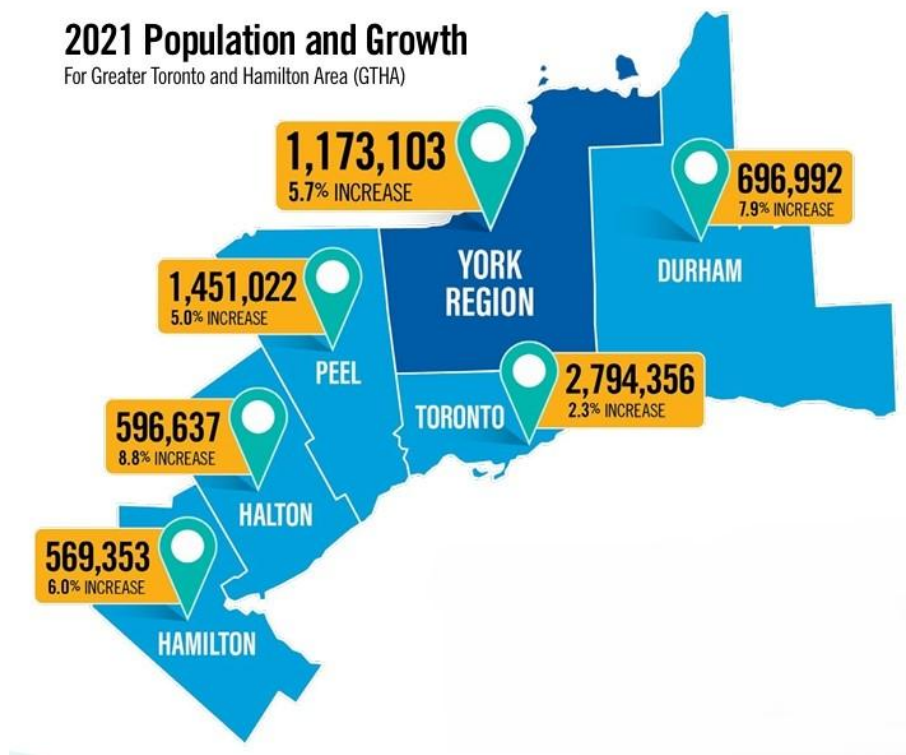


Figure 1: Regions of the Greater Toronto and Hamilton Area

Figure 1 is extracted from the document “Understanding York Region’s Population” and shows the regions of the GTHA, highlighting the York Region in dark blue. Populations and 2021 population growth are displayed (shown as percentage increase) (York Region, 2022).

3.3 Greenery Cover Scenarios

The proposed urban upgrading plans in the case study of York Region by Dardir and colleagues (2023) focused on enhancing greenery coverage with guidance from York Region’s planners and

health experts. Two types of vegetation were considered: ground vegetation cover (GVC) – like grass and shrubs – and tree canopy coverage (TC), which together comprise greenery cover (GC) and provide shade and cooling through evapotranspiration. The existing greenery proportions in a study neighbourhood of Markham Village served as a baseline for comparing two future scenarios. The moderate greenery cover (moderate GC) scenario aimed at achieving approximately 50% of the maximum greenery targets, offering partial shading. In contrast, the intense greenery cover (intense GC) scenario aimed at achieving the full allowable coverage, maximizing shading – especially over roads and buildings. These scenarios, including the reference case, were inputs for a simulation model to assess microclimate impacts in the study by Dardir and colleagues (2023). The results were used as inputs for the CBA of this study. In order to achieve intense TC in the reference neighbourhood of Markham Village, it was suggested that full coverage of roads would be required, requiring new urban design. Figure 2 shows examples in Canadian and US cities of intense TC (Dardir, Umberto, et al., 2023). The cost of new urban design was not included in the CBA of this study. The intense coverage scenario would add approximately 1.9 square kilometres of GC to the Markham Village neighbourhood (Dardir, Umberto, et al., 2023). This, along with the data from Table 2, was used to extract estimated coverage areas of GC scenarios.

Table 2: Reference, Moderate, and Intense Greenery Covers

Table 2 shows the percentage of coverage for reference and proposed GC scenarios, broken down into both tree cover (TC) and ground vegetation cover (GVC). This table has been adopted from: “Health-informed predictive regression for statistical-simulation decision-making in urban heat mitigation”, as this was the base study where these greenery cover scenarios were developed and investigated (Dardir, Umberto, et al., 2023).

Buildings	Reference TC	Moderate GVC	Intense GVC	Moderate TC	Intense TC
19.5%	35.7%	53.1%	76.1%	58.8%	81.8%



Figure 2: Examples of Intense Tree Cover

Figure 2 shows visual representations of intense TC in Vancouver, British Columbia, Canada (left) and Tampa, Florida, United States (right). Images are extracted from the study by Dardir and colleagues (2023).

3.4 Research Design and Approach

This study utilized a quantitative research design, guided by a post-positivist paradigm, that used a case study of the York Region to assess the economic viability of enhancing urban GC as a climate mitigation strategy. In accordance with Creswell and Creswell’s (2018) guidelines for quantitative design, the study is framed around clearly defined variables, systematic data collection, and rigorous analytical methods. The design also draws on case study methodologies (R. K. Yin, 2007) to provide an in-depth contextual analysis of the system under investigation.

3.4.1 Overall Research Strategy

The primary strategy of this research was a Cost-Benefit Analysis (CBA). This method was chosen because it allows a systematic comparison between the quantified benefits and costs of various GC scenarios, as well as being a well-established method in both research and policy (Chelli et al., 2025; Hanley & Spash, 1996; Kula, 1994; Secretariat, 2019). The benefits – spanning health outcomes, energy savings, productivity gains, and ecological improvements – were estimated using validated simulation outputs (e.g., Dardir et al., 2023) and economic valuation techniques (e.g., avoided costs and benefit transfer) (Green Analytics, 2020; Hsu & Chao, 2020; Moslehi et al., 2020; Xie et al., 2023). Direct and indirect impacts were considered in a dual analysis of both benefits and costs.

3.4.2 Research Approach

The study approach, illustrated in Figure 3, followed an integrated quantitative approach by combining statistical and simulation modeling for heat and health relating to implementing the GC scenarios (Dardir, Umberto, et al., 2023) with secondary data used to determine the economic value of cost and benefits and preform a CBA.

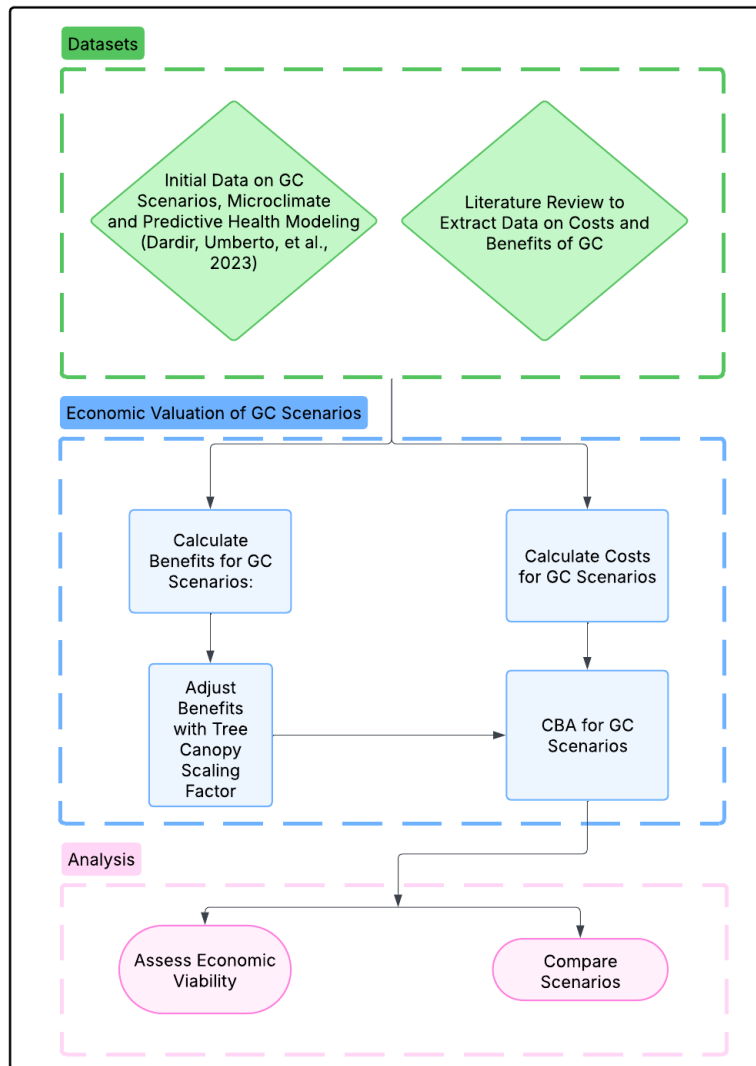


Figure 3: Research Approach

Figure 3 shows the approach used for assessing the economic viability of implementing urban GC as an adaptation and UHI mitigation strategy in York Region.

To achieve a comprehensive valuation of urban GC scenarios, the investigation was divided into three phases:

1. Quantification of Benefits

In this phase, direct and indirect benefit components associated with increasing GC were identified and measured. These include:

- Health benefits: Determined by reduction in emergency department visits, premature mortality, and improved mental well-being
- Energy savings: Estimated through reduced cooling demand
- Productivity gains: Inferred from enhanced workforce efficiency
- Environmental and Ecological benefits: representing gains such as increased air pollutant removal and biodiversity enhancement

The above benefits were included in the estimates of economic benefits of this study; however, other direct and indirect benefits, such as hospital admissions, ambulatory calls, carbon sequestration, and housing valuation, could also be considered (Dardir, Umberto, et al., 2023; J. Wang et al., 2022; S. Yang et al., 2022).

A key innovation to the benefit analysis was the integration of a temporal non-linear factor associated with tree canopy growth. Based on observations in Ontario, where canopy area increases from 1 m² in year 1 to 20 m² in year 20 and reaches 80 m² in year 40 (York Region, 2021), a quadratic function was used to generate a canopy scaling factor. Multiple studies suggest that benefits such as air pollutant removal and cooling scale non-linearly with tree canopy coverage (Nowak et al., 2018; Schwarz et al., 2015; Y. Yin et al., 2024). As the benefits of reduced emergency department visits, avoided premature mortality, energy savings, and productivity gains are all associated with the cooling predictions modelled by Dardir and colleagues (2023) these, as well as estimated air pollutant removal, were adjusted with the canopy scaling factor in order to capture how the magnitude of benefits scales non-linearly as trees mature.

2. Estimation of Costs

In parallel, the cost analysis quantified:

- Installation costs: capital expenses for planting and initial implementation
- Maintenance costs: recurring costs for upkeep (e.g. watering and pruning)

These costs were compiled from municipal and provincial reports, or grey literature where necessary, and were annualized over the expected lifespan of the GC projects, ensuring consistency with economic valuation practices.

3. Cost-benefit Integration

The final phase aggregated the time-series of benefits and costs into overarching economic indicators, including:

- Net Present Value (NPV): calculated by discounting the annual net benefits (benefits minus costs) over the project's life
- Benefit-Cost Ratio (BCR): The ratio of the total discounted benefits to the total discounted costs

3.4.3 Theoretical and Practical Underpinnings

In this study, the CBA framework was employed to evaluate the economic viability of expanded urban GC as a climate mitigation strategy in York Region – a framework that is well-suited to quantify the multifaceted benefits alongside the associated costs (Chelli et al., 2025; Hanley & Spash, 1996; OECD, 2006). The integration of a non-linear canopy growth model builds on the premise that environmental benefits scale with the maturity of urban forests (Barrell, 2018; Nowak et al., 2018). This approach of incorporating a scaling factor is not only theoretically robust – since it captures the dynamics of the tree canopy expansion and its effects on benefits provided by urban GC – but is also practically relevant, given that it is anchored in locally derived empirical data, government policy, and validated simulation models. By triangulating secondary data, government reports, and established economic valuation methods, the research design ensures that findings are both credible and directly applicable to municipal decision-making processes. In essence, this study bridges academic inquiry with practical policy concerns, enabling a comprehensive assessment that informs sustainable urban planning strategies.

3.5 Data Collection

3.5.1 Data on Benefits of GC Scenarios

Direct benefits associated with increasing urban GC include lower emergency department visits, lower energy use, increased productivity, and avoided premature mortality (Dardir, Umberto, et al., 2023). The additional indirect co-benefits of improved biodiversity and air quality were also added to benefit calculations, using secondary data. Further indirect benefits were unable to be included due to a lack of available data. The data surrounding health and heat impacts generated by the modeling simulations of Dardir et al. (2023) was used to quantify the benefits of the GC scenarios. All figures collected from literature that were used in benefit transfers were converted to current 2025 values using consumer price index (CPI) data from the Bank of Canada to adjust for inflation (Bank of Canada, n.d.).

3.5.1.1 Health Benefits

3.5.1.1.1 Reduced Emergency Department Visits

The economic benefits associated with reduced emergency department visits are realized through decreased emergency department visits resulting in reduced healthcare costs. The change in emergency department visits resulting from increasing GC, as well as the cost per visit, is necessary to quantify this benefit. The change in the number of emergency department visits for both GC scenarios based on the change in climate was extracted from climate modelling data from Dardir and colleagues (2023). The cost of emergency department visits includes both direct costs (such as labour, materials, and equipment) and indirect costs (such as administrative and support services) (CIHI, 2022a). In 2020, the CIHI estimated the average cost of an emergency visit in Ontario at CAD \$226 (CIHI, 2022b; Dardir, Umberto, et al., 2023). Adjusting for inflation using historical Consumer Price Index (CPI) data, the estimated cost is approximately CAD \$270.51 in 2025.

3.5.1.1.2 Avoided Premature Mortality

Premature mortality refers to early or unexpected deaths resulting from various health conditions, environmental factors, or lifestyle choices. Research conducted in the GTA, alongside data from the Public Health Agency of Canada, indicated that premature deaths account for approximately 37% of all-cause mortality (Dardir, Umberto, et al., 2023; Dardir, Wilson, et al., 2023; Public Health Agency

of Canada, 2017). The estimated economic value of preventing premature mortality in 2025 was CAD \$9.6 million, derived from Health Canada's assessment of air pollution-related health impacts, which previously valued the avoidance of premature death at CAD \$7.5 million in 2016 (Health Canada, 2021). The valuation approach originates from studies by Chestnut and Civita (2009), who investigated Canadians' willingness to pay to reduce the risk of premature death by 1 in 100,000. As emphasized by Health Canada, this value does not represent the economic worth of an individual's life, but rather it reflects the aggregate financial commitment individuals are willing to make for incremental reductions in mortality risk (Health Canada, 2021). This methodology has been adopted for policy analysis by Health Canada, the Organization for Economic Co-operation and Development (OECD), as well as the U.S. Environmental Protection Agency (EPA) for estimating the economic implications of premature mortality risk (Health Canada, 2021; OECD, 2011; U.S. Environmental Protection Agency, 2001).

3.5.1.1.3 Improved Mental Well-being

Previous studies have established that the presence of open space in a neighbourhood has been shown to increase mental well-being by 0.15 points as measured by the Warwick-Edinburgh Mental Well-being Scale (WEMWBS) (Wood et al., 2017). Utilizing the same methodology as Wilson and Xiao (2023), this is converted to a 0.2 percentage point of improvement, and it is assumed that residents will see a 0.2% improvement in mental health condition due to the increase in GC. The economic burden of mental illness is extracted from the study by Lim and colleagues (2008), assessing the economic burden of mental illness in Canada, including health service utilization, long-term and short-term work loss, as well as health-related quality of life for both diagnosed and undiagnosed mental illnesses. It was found that the total economic burden per capita for 2003 was CAD \$1901.25 (K. L. Lim et al., 2008). Based on this, the annual economic burden of mental illness in Canada is CAD \$2,353.20 per person in 2025. This figure was then used along with the estimated population of 1,173,103 adopted from York Region reporting (2022) to estimate the avoided costs of mental health expenditures for each scenario.

3.5.1.2 Reduced Energy Usage

Energy savings are attributed to reduced energy consumption associated with cooling purposes due to reduced heat provided by increasing greenery cover. The shading and cooling effects provided by increased TC and GVC reduce cooling-related energy usage, such as air conditioning (Berardi et al.,

2020; Dardir & Berardi, 2021). Using climate simulation modelling from Dardir and colleagues (2023), the neighbourhood energy consumption was predicted for both scenarios. Ontario Energy Board (OEB) rates are updated yearly, and the most recent rates released in 2024 were used to estimate energy savings (Ontario Energy Board, 2024). Following a similar methodology to Dardir and colleagues (2023), the OEB pricing rates were considered, and the mid-peak rate was used. The energy price used in the analysis was CAD \$0.122 per kWh.

3.5.1.3 Increased Productivity

Rises in temperatures have been found to negatively impact worker concentration and irritability, leading to reduced efficiency and productivity (Government of Canada, 2018). During the summer months, outdoor workers in industrial sectors experience an average annual productivity loss of 22 hours due to extended breaks necessitated by heat exposure (CIHI, 2022a). This lost time accounts for approximately 1% of total annual work hours and, given the average hourly wage in Ontario of CAD \$36.14 (Government of Ontario, 2024). This translates to an annual economic loss of approximately CAD \$795.08 per affected worker in 2025.

To estimate the number of individuals exposed to direct heat-related risks in the workplace, research utilizing the Canadian Carcinogen Exposure Database suggests that 8.8% of Ontario's labour force is employed in professions associated with hazardous exposure to ultraviolet solar radiation (Peters et al., 2015). The York Region 2016 Census Release Report indicated that 67% of the regional population was part of the labour force. Applying this same labour participation rate to the estimated population of 1,173,103 adopted from York Region reporting (2022), and an assumed equivalent exposure to ultraviolet radiation, an estimated 69,166 workers were at significant risk of solar radiation exposure during work hours, contributing to potential productivity declines.

3.5.1.4 Environmental and Ecological Benefits

3.5.1.4.1 Air Quality

The economic benefits associated with improved air quality are realized through the removal of air pollutants by trees and the value associated with avoided health implications, such as respiratory illness and hospital admissions. Studies of 86 Canadian cities indicated that urban forest—as a baseline—is estimated to remove around 16,500 metric tonnes of air pollution per year. The avoided cost provided by pollutant removal is valued at approximately CAD \$511 (2010) per hectare on

average (Nowak et al., 2018). Adjusting for inflation using historical Consumer Price Index (CPI) data, the estimated value is approximately CAD \$722.74 per hectare in 2025, which is equivalent to an average value of \$72,274 per square kilometre of tree cover.

3.5.1.4.2 Biodiversity

The economic benefits associated with biodiversity were assessed through the indicator of increased bee diversity and the associated value of pollination services, adapted from the methods used in the “Ontario’s Wealth, Canada’s Future” Report (S. Wilson, 2008). Brasil and colleagues (2023) found that medium urbanization intensity (defined by 25-75% impervious surface area) increased wild bee abundance more than low urbanization intensity (defined by less than 25% impervious surface area) by approximately 79% and 31% respectively, as compared to high urbanization intensity. These increases in bee abundance were associated with corresponding GC scenarios in this study. It has been estimated that bees are responsible for approximately 70% of North American pollination services (Seeds of Diversity, 2024). Pollinators increase crop yields and product quality, and it is estimated that a minimum of 20% of global food crops require insect pollinators (Klein et al., 2006). These percentages were used to adjust the value of the direct farm operating revenue of CAD \$390 million (2011) in York Region (York Region, 2024b). Adjusting for inflation using historical Consumer Price Index (CPI) data, the estimated direct farm operating revenue is approximately CAD \$551.6 million in 2025.

3.5.2 Data on Costs of GC Scenarios

Cost data was broken down into two categories. First, installation costs, which are one-time capital expenditures and include expenses related to planting and site preparation. Data was extracted from financial tools and literature that were contextually relevant and is further detailed below. Second, maintenance costs, which are annual operating expenses (e.g., watering and pruning), were obtained from the York Region budget (York Region, 2024a).

3.5.2.1 Data on Costs of Installing Tree Cover

Based on an average of ten years of planting activity in Southern Ontario to achieve the 50 million tree objective (Green Analytics, 2019, p. 4), the average number of trees per hectare was obtained and then converted to trees per square kilometre (see Table 3). Secondary data from the survey of ten planting delivery agents (PDA) was also extracted from the report by Green Analytics. The average

cost per tree found was \$2.81 in 2018, and this is said to include administrative, material, labour, equipment, and site preparation costs (Green Analytics, 2019, p. 5). Once adjusted for inflation, it is estimated that the average cost per square kilometre of tree installation is \$603,555.48 in 2025. No data was available from regional or municipal planning, nor was more contextually relevant data found in the literature review.

Table 3: Installing Tree Cover

Table 3 is adapted from the report on The Economic Value of Tree Planting in Southern Ontario (Green Analytics, 2019, pp. 4–5). This report summarizes the number of trees planted and the area planted over a ten-year period, as well as installation cost estimates. The average number of trees per hectare was extracted and converted to trees per square kilometre. Cost was adjusted to 2025 value.

	Year	Trees Planted	Area (hectares)	Trees/ hectare
	2008	1,275,326.00	697.26	1,829.05
	2009	2,005,777.00	1121.49	1,788.49
	2010	2,054,032.00	1157.92	1,773.90
	2011	2,531,260.00	1410.70	1,794.33
	2012	2,671,631.00	1431.14	1,866.79
	2013	2,355,057.00	1274.25	1,848.19
	2014	2,272,465.00	2736.25	830.50
	2015	2,464,069.00	1314.00	1,875.24
	2016	2,431,512.00	1329.84	1,828.42
	2017	2,123,710.00	1140.88	1,861.47
	2018	2,247,013.00	1187.79	1,891.76
	total	24,431,852.00	14801.52	
Average trees/hectare				1,744.38

trees/km ²		174,438
Average cost/tree (2018)		\$2.81
Average cost/tree (2025)		\$3.46
Estimated cost of tree planting/km ² (2025)		\$603,555.48

3.5.2.2 Data on Costs of Installing GVC

Data for the cost of installation of GVC was obtained from the Toronto and Region Conservation Authority (TRCA) Low Impact Development Life Cycle Costing Tool (LID LCCT) (TRCA, 2018). This tool helps planners, consultants, and municipalities to plan and assess the financial costs of LID methods, including bioretention and stormwater landscaping (see Figure 4) (TRCA, 2018, 2025). The relevant cost data for installing these types of GVC was extracted from the LID LCCT. Costs for aspects relating directly to drainage were not included, as the focus of the scenarios being assessed in this thesis is on heat mitigation. Therefore, only installation costs relating to labour, equipment, and materials (e.g., plants) were included in the installation costs (see Table 4 for a break down of cost components). Using the costing tool, it is assumed that one cubic meter must be excavated per square meter of proposed project, and that a modest one-hour work is required per square meter, the total estimated GVC costs per unit (square meter) is \$330.39, plus a base rate of \$3793.20 per project (see Table 4).



Figure 4: Grass Filter Strip and Bioretention

Figure 4 shows two types of GVC used in stormwater landscaping by the TRCA. Grass filter strip (left) and bioretention cell (right). Images are from the LID LCCT (TRCA, 2018).

Table 4: Summary of GVC Costs

Table 4 summarizes GVC costs extracted from the TRCA Low Impact Development Life Cycle Costing Tool (2018) as applicable to the below-mentioned aspects of the projects. Costs are presented in 2025 CAD.

<i>Cost Component</i>	<i>Unit</i>	<i>Cost per unit (\$)</i>
<i>Excavation</i>	m ³	3.19
<i>Loading</i>	m ³	0.48
<i>Hauling</i>	Hours	240.66
<i>Vegetation</i>	m ²	86.06
<i>Project Inspections and Administrative Costs</i>	Per project	2702.62
<i>Safety fencing</i>	1 week rental	1090.58
<i>Total</i>		\$3793.20 + \$330.39/ m ²

3.5.2.3 Data on Maintenance Costs

Based on the York Region's budgeting data, the annual maintenance cost of tree boulevard planters and landscaped centre medians varies from \$2,000 to \$131,000 per square kilometre based on location factors (York Region, 2024a). To estimate maintenance costs for the region, an average annual maintenance cost of \$67,000 per square kilometre was obtained.

3.6 Data Analysis and Equations

All figures collected from literature that were used in benefit transfer and avoided cost methods were converted to current 2025 values using the consumer price index (CPI) data from the Bank of Canada to adjust for inflation.

3.6.1 Analysis of Economic Benefits of GC

The well-known and validated direct cost-savings approach was used to quantify the health, productivity, and energy benefits of GC scenarios (Moslehi et al., 2020; Xie et al., 2023). Indirect benefits of biodiversity and air pollutant removal were calculated using a benefit transfer method from relevant and reputable academic literature sharing a similar context and socio-economic conditions. All benefits were calculated per annum, which were then projected to value the benefits during the expected life of the proposed scenarios. Based on the literature review, a commonly used life expectancy of NbS in assessments is 40 years (Hsu & Chao, 2020; McPherson et al., 2006). This 40-year project life expectancy was adopted for valuation, given the canopy growth rate is not known beyond the 40-year time horizon.

3.6.2 A Generalized Benefit Function for GC

Adapted from Dardir and colleagues (2023), the overall annual economic benefit (EB) is equal to the sum of each benefit category calculated for a prospective year (t) by considering health benefits (EB_{health}), energy cost savings (EB_{energy}), increased productivity (EB_{prod}), and environmental and ecological benefits (EB_{eco}) (see Equation 1). Methodology for quantifying EB_{energy} and $EB_{productivity}$ was directly adapted from Dardir and colleagues, utilizing the statistical modeling data and formulas (Dardir, Umberto, et al., 2023).

Equation 1

$$EB_{annual}(t) = EB_{health}(t) + EB_{energy}(t) + EB_{prod}(t) + EB_{eco}(t)$$

Where:

EB_{annual} = the overall estimated annual economic benefit for a prospective year (t),

EB_{health} = the sum of health benefits,

EB_{energy} = the estimated energy cost savings,

EB_{prod} = the estimated increased productivity benefits, and

EB_{eco} = the estimated value of environmental and ecological benefits.

3.6.3 Incorporating Non-Linear Tree Canopy Growth

Multiple studies note that benefits such as cooling and air pollutant removal scale non-linearly with tree canopy coverage (Nowak et al., 2018; Schwarz et al., 2015; Y. Yin et al., 2024). The benefits of reduced emergency department visits, avoided premature mortality, energy savings, and productivity gains are all associated with the cooling predictions modelled by Dardir and colleagues (2023)

Therefore, these, as well as estimated air pollutant removal were adjusted with the canopy scaling factor in order to capture how the magnitude of benefits scales non-linearly as trees mature. In this study, the observed canopy coverage (CC) growth adapted from York Region's State of the Forest report (2021) is used to create a scaling function as follows:

$CC(1) = 1 \text{ m}^2$ at year 1

$CC(20) = 20 \text{ m}^2$ at year 20

$CC(40) = 80 \text{ m}^2$ at year 40

To model this non-linear growth, a quadratic function for the effective canopy area $CC(t)$ (in m^2) at time t is assumed:

$$CC(t) = at^2 + bt + c,$$

subject to the boundary conditions:

$$\left\{ \begin{array}{l} a + b + c = 1, \\ 400a + 20b + c = 20, \\ 1600a + 40b + c = 80 \end{array} \right.$$

Solving this system yields:

$$a = \frac{2}{39} \approx 0.05128,$$

$$b = -\frac{1}{13} \approx -0.07692,$$

$$c = \frac{40}{39} \approx 1.02564$$

Thus, the canopy scaling factor is:

$$f_{canopy}(t) = CC(t) = \frac{2}{39}t^2 - \frac{1}{13}t + \frac{40}{39}$$

Assuming that benefits are not fully realized until 40 years, the normalized canopy scaling factor is now defined as:

$$f_{canopy}(t) = \begin{cases} \frac{CC(t) - CC(1)}{CC(40) - CC(1)} = \frac{CC(t) - 1}{80 - 1} = \frac{CC(t) - 1}{79}, & \text{for } t \leq 40 \\ 1, & \text{for } t > 40 \end{cases}$$

Thus, at $t = 1$ we have $f_{canopy}(1) = 0$ (indicating that the benefits are just beginning to accrue), and at $t = 40$ we have $f_{canopy}(40) = 1$. For years beyond 40 the benefits remain at their full value.

3.6.4 Quantifying Health-Related Benefits

Focusing on the economic benefits of health, the total economic benefits of health were then broken into two separate functions: one for traditional health benefits (H_{trad}) – quantified by reduced emergency department visits and reduced premature mortality – and the other for mental health, or wellbeing (H_{well}). Equation 2 shows how the economic benefits of traditional health (H_{trad}) were calculated by summing the benefits of forecasted avoided premature mortality and avoided emergency department visits resulting from microclimate and statistical modeling (see Dardir et al., 2023) and adjusting for canopy growth.

Equation 3 shows how the economic benefits of wellness were calculated, which is not adjusted for canopy cover growth. Together, the sum of traditional health benefits (H_{trad}) and mental health benefits (H_{well}) equals the total economic benefits of health (EB_{health}) (see Equation 4).

Equation 2

$$H_{trad}(t) = [(\Delta ED_t \times c_{ED}) + (\Delta Mortality_t \times VSL)] \times f_{canopy}(t)$$

Where:

ΔED = the reduction in emergency department (ED) visits,

c_{ED} = the cost saved per visit,

$\Delta Mortality$ = the reduction in mortality

VSL = the Value of Statistical Life, and

f_{canopy} = the canopy scaling factor at time (t).

Equation 3

$$H_{well}(t) = \Delta Wellbeing_t \times c_{wellbeing}$$

Where:

$\Delta Wellbeing$ = the quantified improvement in mental wellbeing at time (t), and

$c_{wellbeing}$ = the corresponding monetary value per unit change.

Thus, the overall health benefits function (EB_{health}) becomes:

Equation 4

$$EB_{health}(t) = H_{trad}(t) + H_{well}(t)$$

$$EB_{health}(t) = [(\Delta ED_t \times c_{ED}) + (\Delta Mortality_t \times VSL)] \times f_{canopy}(t) + \Delta Wellbeing_t \times c_{wellbeing}$$

3.6.5 Quantifying Productivity Benefits

Productivity gains, reflecting improvements in work performance from better environmental conditions (as modelled by Dardir and colleagues, 2023), are given by:

Equation 5

$$EB_{prod}(t) = (\Delta H(t) \times P_{loss/worker/hot\ day} \times C_w) \times f_{canopy}(t)$$

Where:

ΔH = the change in hot days as modelled,

Ploss = the percentage of labour force exposed to dangerous solar radiation that was expected to lose working hours on hot days

Cw = the cost per worker in productivity loss

3.6.6 Quantifying Energy Saving Benefits

The energy savings component was estimated by converting the reduction in energy consumption from lower cooling demand into monetary savings using the following equation:

Equation 6

$$EB_{energy}(t) = (E \text{ savings daily (kWh)} \times Ddays \times Price/kWh) \times f_{canopy}(t)$$

Where:

E savings daily (kWh) = estimated daily energy savings in kilowatt hours (kWh) based on modeling (Dardir et al., 2023),

Ddays = the number of days in a typical summer season

Price/kWh = the current energy pricing.

3.6.7 Quantifying Environmental and Ecological Benefits

The economic benefits associated with environmental and ecological benefits (EB_{eco}) for this study include two separate components: air pollutant removal (EB_{AP}) and biodiversity enhancement (EB_{biod}).

Based on the data from Nowak and colleagues (2018), air pollution removal is valued at an average of \$72,274 per square kilometre of tree cover. Incorporating the impact of changing tree coverage with the GC scenarios and canopy growth, the economic benefit from pollutant removal is given by:

Equation 7

$$EB_{AP}(t) = TC \times Vp \times f_{canopy}(t)$$

Where:

TC = tree canopy coverage area in square kilometres,

Vp = value of pollutant removal provided by the trees per square kilometre (\$72,274)

Additional benefits are associated with the pollination services provided by increased abundance and diversity of bees, which have shown links to urban greenery cover (Brasil et al., 2023; Klein et al., 2006; Seeds of Diversity, 2024). The following equation is adapted from a study on “Canada’s Wealth and Natural Capital” (S. Wilson, 2012) and expanded using the anticipated change in wild bee abundance due to changes in urbanization intensity and the percentage of pollinating services provided by bees.

Equation 8

$$EB_{biod} = R \times \Delta A \times P \times D$$

Where:

R = the direct farm operating revenue,

ΔA = the change in wild bee abundance due to changes in urbanization intensity,

P = the percentage of pollinating services provided by bees,

D = the percentage of crops dependent on insect pollinators.

The overall environmental and ecological benefit is the sum of the air pollutant removal and biodiversity components:

Equation 9

$$EB_{eco}(t) = EB_{AP}(t) + EB_{biod}$$

3.6.8 Economic Costs of Greenery Cover

3.6.9 A Generalized Cost Function for GC

Economic Costs (EC) of GC are equal to the sum of the cost components that compose GC, which include costs required to establish it as well as maintain it over time. Adapted from Panduro and colleagues (2024), the cost function is as follows:

Equation 10

$$EC = o + Cs + Vs + \sum_{t=1}^T m_t$$

Where:

o = the land opportunity cost,

C_s = the installation cost of TC (where C equals the costs of installation per square kilometre and s equals the number of square kilometres),

V_s = the installation cost of GVC (where V equals the costs of installation per square kilometre and s equals the number of square kilometres),

m = the maintenance costs over time period (T) in years (t)

3.6.10 CBA Analysis

3.6.11 Net Present Value

CBA was completed by evaluating two indicators. First, the Net Present Value (NPV) was used as a performance metric in terms of the proposed GC scenario's economic value, defined as the difference between total benefits and costs (Verlicchi et al., 2012). Although discount rates vary greatly in the literature and the use of discounting is debated, a social discount rate of 3% is used, as is by Canadian federal government in assessment of environmental projects and policies (Secretariat, 2019). The NPV equation (Equation 11) is adopted from Secretariat (2019), where the NPV is equal to the sum of economic benefits (B) minus the sum of costs (C). C_t and B_t respectively are costs and benefits in the year (t), and (T) is the expected lifespan of the GC scenario.

Equation 11

$$NPV = \sum_{t=1}^T (B_t - C_t) / (1 + r)^t$$

Where:

B = benefits,

C = costs,

r = discount rate,

t = the period of analysis (year), and

T = the expected lifespan of the scenario (or total number of periods).

If NPV is greater than or equal to 0, the project is deemed acceptable to implement from an economic standpoint. If NPV is less than 0, the costs outweigh the benefits and project investment should be rejected (Hanley & Spash, 1996; OECD, 2006; Pearce & Turner, 1989; Secretariat, 2019; Verlicchi et al., 2012).

3.6.12 Benefit Cost Ratio

Second, the Benefit Cost Ratio (BCR) was considered. This was calculated by benefits divided by the costs (both at present value). Adopted from Verlicchi and colleagues (2012), the equation is as follows:

Equation 12

$$BCR = \frac{\sum_{t=1}^T \frac{B_t}{(1+r)^t}}{\sum_{t=1}^T \frac{C_t}{(1+r)^t} + C_0}$$

Similarly to NPV, it is a general rule to accept projects with a BCR greater than 1, or select the project with the highest BCR when choosing between mutually exclusive project options (OECD, 2006).

3.7 Reliability and Validity

Assessment of reliability requires consideration of how consistent, credible and robust the approach is (Creswell & Creswell, 2018). Firstly, one must consider the data sources used in benefit transfer methodology to ensure validity and reliability. Utilizing data sources which have been assessed for credibility and contextual relevance strengthens the value transfer method's validity (Green Analytics, 2020). Additionally, assumptions made in valuation are backed with evidence where possible to strengthen assessment validity. By creating an economic model for GC scenario valuation using established approaches from academia and government, the credibility and reliability of the model are strengthened. Furthermore, inclusion of all costs and benefits that have been established in literature as key features in valuation and that have available data for the region, the model becomes more robust, which improves reliability. The inclusion of the tree canopy scaling factor also strengthens the model, improving reliability. Overall, the credible sources for data, as well as

approach, assumptions backed with evidence, and inclusion of a wide range of factors established as necessary for valuation, all aid in strengthening the reliability of this methodology.

3.8 Limitations

The CBA of NbS can provide valuable insights into environmental and economic trade-offs; however, several methodological, scope, and data-related constraints must be acknowledged. These limitations impact the comprehensiveness and accuracy of valuation, necessitating careful interpretation and future research to further refine methodologies and the inclusion of benefit categories.

One key limitation lies in the monetization of ecosystem services (ES), which inherently restricts the ability to capture their full environmental and social value (Kula, 1994; Panduro et al., 2024). Despite the long-standing methodologies for economic valuation, there is considerable criticism in their usage and validity (Kula, 1994). The transfer and avoided cost valuation methodologies have limitations in variation across region/country as well as in project size. However, it can be accounted for by using data from similar contexts and areas with similar socio-economic conditions (Green Analytics, 2020; Panduro et al., 2024). For this study, values were extracted from studies of similar location, context, and socio-economic conditions, helping to minimize this limitation. With few proposed projects offering primary cost data, and limited studies available that estimate costs of installing and maintaining urban GC in Canada, a transfer method demonstrates viable cost valuation. It is also notable that policy and decision-making surrounding ecosystem service valuation requires moderate accuracy, as any minor inaccuracies in valuation may be offset (Liu et al., 2010). Therefore, value transfer can still provide the moderate accuracy required for policy and decision-making purposes.

While traditional CBA frameworks account for direct economic benefits, they frequently overlook indirect and non-market benefits such as improved air quality, biodiversity enhancement, and psychological well-being (World Bank, 2023). Additionally, the valuation of cooling effects provided by urban green spaces remains inconsistent due to variations in local climate conditions and the difficulty of quantifying long-term regulation benefits (Biasin et al., 2023). Valuation techniques and estimation design were based on established methodologies and crafted to support replicability. Yet, reliability could be further strengthened through sensitivity analysis of key variables. Additionally, the tree canopy growth factor and associated tree installation costs could be

strengthened by including species-specific data to better understand how canopy growth impacts benefit realization (Dardir, Umberto, et al., 2023).

Selection bias in determining which benefits and costs are included presents another challenge. Comprehensive datasets are often unavailable for all ES categories, and data is very time-consuming and cost-intensive to collect. This requires reliance on existing data while striving to employ systems thinking to expand the scope where feasible (Secretariat, 2019; United Nations, 2018). While established methods were employed to enhance reliability, certain ES categories were not fully accounted for due to data constraints. Wilson and Xiao (2023) highlight the need for a more comprehensive framework that integrates underrepresented ES categories such as flood mitigation, air purification, and reductions in heat-related illnesses. This study did include a more comprehensive framework; however, not all ES were fully incorporated. For example, indirect benefits of housing valuation, hospital admission, ambulatory calls, improved physical health, carbon sequestration, and flood risk reduction are among some of the potential benefits which could also be included in the framework. Given the omission of these benefits, the results are underestimated. Additionally, the scope of this study is confined to direct and indirect costs and benefits affecting York Region's population and institutions, thereby excluding broader impacts. Broadening the scope and inclusion of cost and benefit categories to the framework may provide additional insights.

Despite these limitations, this study provides a strong foundation for understanding the economic and environmental implications of GC investments in York Region. Future research should focus on further refining valuation methodologies, expanding ES category inclusion, and improving data collection to enhance the accuracy and applicability of economic assessments. By addressing these limitations, policymakers can make more informed decisions that maximize the long-term benefits of NbS investments in mitigating heat impacts and promoting sustainable urban development.

Chapter 4: Results

4.1 Benefit Analysis Results

Note that all results are presented in 2025 Canadian Dollars.

4.1.1 Health Benefit Estimation

4.1.1.1 Decreased Emergency Department Visits

Using the statistical modelling and microclimate simulation results from Dardir and colleagues (2023) as well as the avoided cost methodology, emergency department visits were calculated as follows:

4.1.1.1.1 Moderate Coverage Scenario

Based on a 150-day summer season and the predicted reduction of 1.1 all-cause emergency visits attributed to the moderate coverage scenario, there is an expected total reduction of 165 emergency department visits during a typical summer season (Dardir, Umberto, et al., 2023). Using the avoided cost method and adopting the economic cost of emergency department visits of CAD \$270.51 (2025), the base economic benefit at full (mature) level of canopy coverage for reduced emergency department visits is estimated to be \$44,634.15 annually (see Table 5 for more information on annual benefits)

4.1.1.1.2 Intense Coverage Scenario

The predicted reduction in emergency room visits for 2030 based on statistical and microclimate modelling was 465 on average (Dardir, Umberto, et al., 2023). Using the value avoided cost method and adopting the economic cost of emergency department visits of CAD \$270.51 (2025), the base economic benefit at full (mature) level of canopy coverage for reduced emergency department visits is estimated to be \$125,787.15 annually (see Table 5 for more information on annual benefits)

4.1.1.2 Avoided Premature Death

4.1.1.2.1 Moderate Coverage Scenario

Reported all-cause mortality was reduced by a maximum of 0.2 per day, with estimated results of 30 fewer deaths per typical summer season (150 days), per year when applying the moderate GC scenario (Dardir, Umberto, et al., 2023). Assigning the established proportional factor of premature

mortality within all cause mortality (37%), approximately 11 fewer premature deaths are expected annually per summer season (Dardir, Umberto, et al., 2023). Using the adopted value of avoiding premature death of approximately \$9.6 million (Health Canada, 2021), the total estimated base economic benefit of avoided premature mortality is \$105.5 million annually at the full (mature) level of canopy coverage in the moderate GC scenario (see Table 5 for more information on annual benefits).

4.1.1.2.2 Intense Coverage Scenario

Reported all-cause mortality was reduced by a maximum of 0.4 per day, with estimated results of 60 fewer deaths per typical summer season (150 days), per year when applying the intense GC scenario (Dardir, Umberto, et al., 2023). Assigning the established proportional factor of premature mortality within all cause mortality (37%), approximately 22 fewer premature deaths are expected annually per summer season (Dardir, Umberto, et al., 2023). Using the adopted value of avoiding premature death of approximately \$9.6 million (Health Canada, 2021), the total estimated base economic benefit of avoided premature mortality is \$211.2 million annually at the full (mature) level of canopy coverage (see Table 5 for more information on annual benefits).

4.1.1.3 Improved Mental Wellbeing

The economic value of improved mental health is extracted from the study by Lim and colleagues (2008), assessing the economic burden of mental illness in Canada, including health service utilization, long-term and short-term work loss, as well as health-related quality of life. Based on this, the economic burden of mental illness in Canada is \$2,353.20 per person per year in 2025 CAD. GC is expected to improve mental well-being by 0.2%, and the York Region population is currently estimated at 1,173,103 (Wood et al., 2017; York Region, 2022). Thus, by applying Equation 3 improved mental well-being among residents of the investigated region by increasing GC is equivalent to an estimated avoided economic burden of CAD \$5.5 million annually in 2025. Because the previous study by Wood and colleagues (2017) regarding mental health benefits was not based on the size, but simply the presence of GC or park space, this figure is seen as applicable to both moderate and intense GC scenarios.

4.1.2 Energy Savings Estimation

4.1.2.1 Moderate Coverage Results

By applying the moderate GC scenario, average daily energy consumption was reduced by 80.8 MW in the investigated neighbourhood during a typical summer season (Dardir, Umberto, et al., 2023). Based on the assumed energy pricing of \$0.122/kWh, daily savings in energy consumption attributed to the moderate GC scenario during a typical summer season are CAD \$410.73. A typical summer season assumes 150 days (D_{days}) of operation. Based on the assumption that the investigated neighbourhood hosts 0.5% of the total population of the region, the energy savings for the entire region can be calculated as 200 times the average savings in the neighbourhood, assuming the neighbourhood is representative of the entire region. By applying Equation 6, the anticipated annual economic benefits in York Region due to energy savings attributed to the moderate GC scenario are CAD \$12.3 million at the full (mature) level of canopy coverage (see Table 5 for more information on annual benefits).

4.1.2.2 Intense Coverage Results

By applying the intense GC scenario, average daily energy consumption was reduced by 246 MW in the investigated neighbourhood during a typical summer season. Based on the assumed energy pricing, daily savings in energy consumption attributed to this intense GC scenario during a typical summer season are CAD \$1250.50. A typical summer season assumes 150 days (D_{days}) of operation. Based on the assumption that the investigated neighbourhood hosts 0.5% of the total population of the region, the energy savings for the entire region can be calculated as 200 times (θ) the average savings in the neighbourhood, assuming the neighbourhood is representative of the entire region. By applying Equation 6, the anticipated annual economic benefits in York Region due to energy savings attributed to the moderate GC scenario are CAD \$37.5 million at the full (mature) level of canopy coverage (As adapted from Dardir et al., 2023 and adjusted for current energy pricing) (see Table 5 for more information on annual benefits).

4.1.3 Increased Productivity Estimation

4.1.3.1 Moderate Coverage Results

The following is adapted from the analysis by Dardir and colleagues (2023). Based on historical measurements from 2010, the GTA has 20 days per summer with ambient temperatures greater than 30 degrees Celsius. Assuming economic loss of CAD \$795.08 per outdoor worker per annum, and loss of working hours on hot days, the loss in productivity was estimated at CAD \$39.75 per hot day per outdoor worker. Based on the microclimate modelling results by Dardir and colleagues (2023), the application of the moderate GC scenario reduced the number of hot days by 4. Therefore, by applying Equation 5, the intense GC scenario results in avoided productivity loss of \$159.02 per outdoor worker per annual summer season. Based on the percentage of the labour force exposed to dangerous solar radiation, the avoided productivity losses attributed to the moderate GC scenario in a typical summer season are approximately CAD \$11 million as a base rate at full (mature) canopy coverage (see Table 5 for more information on annual benefits).

4.1.3.2 Intense Coverage Results

The following is adapted from the analysis by Dardir and colleagues (2023). Based on historical measurements from 2010, the GTA has 20 days per summer with ambient temperatures greater than 30 degrees Celsius. Assuming economic loss of CAD \$795.08 per outdoor worker per annum, and loss of working hours on hot days, the loss in productivity was estimated at CAD \$39.75 per hot day per outdoor worker. Based on the microclimate modelling results by Dardir and colleagues (2023), the application of the intense GC scenario reduced the number of hot days by 10. Therefore, by applying Equation 5, the intense GC scenario results in avoided productivity loss of \$397.50 per outdoor worker per annual summer season. Based on the percentage of the labour force exposed to dangerous solar radiation, the avoided productivity losses attributed to the intense GC scenario in a typical summer season are approximately CAD \$27.5 million as a base rate at full (mature) canopy coverage (see Table 5 for more information on annual benefits).

4.1.4 Environmental and Ecological Benefit Estimation

4.1.4.1 Increased Biodiversity Estimation

Based on a study in the city of Toronto investigating the abundance of pollinating bee species in urban areas and the change in abundance based on increased green space in surrounding areas (Brasil et al., 2023), as well as the economic value of pollination for crops in York Region, the estimated value of this service is as follows:

4.1.4.1.1 Moderate Coverage

Medium urbanization intensity, defined by 25-75% impervious surface area (vs. green space), increases wild bee abundance by approximately 79% over highly urbanised areas (defined by more than 75% impervious surface area (Brasil et al., 2023)). Assuming that this medium urbanization intensity is similar in intensity to the moderate coverage scenario, it is assumed that the moderate coverage scenario would result in an increase in wild bee abundance of 79%. Bees are responsible for approximately 70% of North American pollination services (Seeds of Diversity, 2024). Pollinators increase crop yields, product quality, and the estimation that a minimum of 20% of global food crops require insect pollinators (Klein et al., 2006). Given this and the \$551.6 million (2025) value of direct farm operating revenue in York Region (York Region, 2024b), the value of wild bee pollinators using Equation 8 is estimated at \$61 million annually for York Region as a base annual rate at full (mature) canopy coverage.

4.1.4.1.2 Intense Coverage

Low urbanization intensity, defined by less than 25% impervious surface area (vs. green space), increases wild bee abundance by approximately 31% as compared to a highly urbanized area (Brasil et al., 2023). Assuming that this low urbanization intensity is consistent with the intense coverage scenario, it is assumed that the intense GC scenario would result in an increase in wild bee abundance of 31%. Bees are responsible for approximately 70% of North American pollination services (Seeds of Diversity, 2024). Pollinators increase crop yield, product quality, and the estimation that a minimum of 20% of global food crops require insect pollination (Klein et al., 2006). Given this and the \$551.6 million (2025) value of direct farm operating revenue in York Region (York Region, 2024b), the value of wild bee pollinators using Equation 8 is estimated at \$23.9 million annually for York Region as a base annual rate at full (mature) canopy coverage.

4.1.4.2 Air Pollutant Removal

4.1.4.2.1 Moderate Coverage

Based on the data from Nowak and colleagues (2018), a baseline urban forest is estimated to remove around 16,500 metric tonnes of air pollution per year, which is valued at approximately CAD \$72,274 per square kilometre of tree coverage in 2025 (Nowak et al., 2018). Using the information about neighbourhood size and coverage in the report from Dardir and colleagues (2023), it is estimated that the moderate coverage scenario (increasing from 35.7% to 58.8% GC) requires an additional coverage of approximately 0.95 km² at the neighbourhood level. If we assume that the entire increased GC area will contain TC, and this scenario is then applied to the entire region, with a total land area of 1758.27 km², then the estimated value of moderate coverage at the regional level is \$74,654,705.56 as a base annual rate at full (mature) canopy coverage.

4.1.4.2.2 Intense Coverage

Based on the data from Nowak and colleagues (2018), a baseline urban forest is estimated to remove around 16,500 metric tonnes of air pollution per year, which is valued at approximately CAD \$72,274 per square kilometre of tree coverage in 2025 (Nowak et al., 2018). Using the information about neighbourhood size and coverage in the report from Dardir and colleagues (2023), it is estimated that the intense coverage scenario (increasing from 35.7% to 81.8% GC) requires an additional coverage of approximately 1.9 km² at the neighbourhood level. If we assume that the entire increased GC area will contain TC, and this scenario is then applied to the entire region, with a total land area of 1758.27 km², then the estimated value of moderate coverage at the regional level is \$103,949,154.49 as a base annual rate at the full (mature) canopy coverage.

4.1.5 Total Economic Benefit

4.1.5.1 Base Rate

The total economic benefit is equal to the sum of all benefits of the moderate GC scenario. That is, it is equal to the total health benefits, plus the increased productivity benefits, plus the energy savings, plus the total environmental and ecological benefits (see Equation 1). At a base rate assuming full canopy coverage, the total sum of economic benefits (EB) is estimated at approximately \$270 million

annually for the moderate coverage scenario and \$409 million for the intense coverage scenario. See Table 5 for more details.

4.1.5.2 Adjustment for Canopy Growth

Benefits of reduced emergency department visits, avoided premature mortality, energy savings, productivity gains, and air pollutant removal were all adjusted with the canopy scaling factor to demonstrate how the magnitude of benefits scales with tree maturity over time. As the benefit of mental well-being is not associated with canopy growth, this benefit value was not scaled over time and remains constant. Figure 5 shows the increase of annual benefit values for both scenarios over time as a result of canopy cover growth. A full table of discounted annual benefits can be found in Appendix A (see Table 8). The full expected value of benefits over the 40-year lifespan is approximately \$3.8 billion for the moderate scenario and \$5.7 billion for the intense scenario without adjustment for inflation or discounting.

Table 5: Summary of Estimated Annual Benefits

Table 5 provides a summary of estimated annual regional benefits for both the moderate and intense GC scenarios. All benefits are annual base rates at full (mature) canopy coverage, without adjustment for canopy growth or inflation over time. All values are presented in 2025 CAD.

Benefit Category	Description	Moderate GC Value	Intense GC Value
Health Benefits	Cost savings due to reduction in emergency department visits, decreased premature mortality, and improved mental well-being	\$ 111,028,978.62	\$ 216,573,384.13
Energy Savings Benefit	Cost Savings due to lower energy consumption (e.g. reduced cooling demands from lower urban heat)	\$ 12,322,000.00	\$ 37,515,000.00
Productivity Benefit	Cost savings from the avoided loss of work hours from heat stress	\$ 10,997,418.31	\$ 27,493,545.77
Environmental and Ecological Benefits	Estimated value of pollination services provided by increased bee abundance and diversity; estimated value of improved air quality	\$ 135,661,703.83	\$ 127,888,609.51
TOTAL BENEFITS		\$ 270,010,100.76	\$ 409,470,539.41

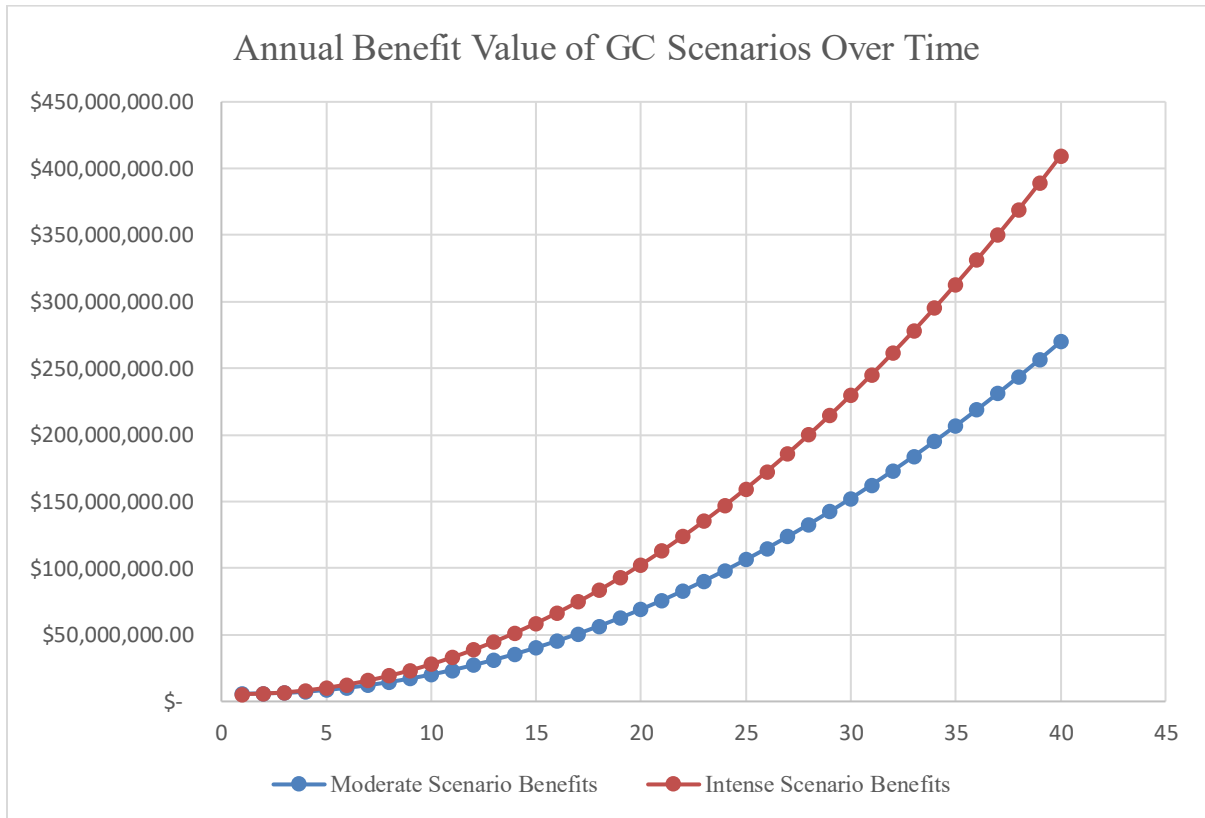


Figure 5: Annual Benefit Value of GC Scenarios Over Time When Adjusted to Account for Canopy Growth

Figure 5 demonstrates how the total benefit value grows over time when adjusted with the canopy scaling factor. Moderate GC scenario benefit values are shown in blue, and intense GC scenario benefit values are shown in red. Annual benefit values are shown in 2025 CAD over the 40-year expected lifespan without discounting.

4.2 Cost Analysis Results

Below installation and maintenance costs for GC scenarios are detailed. It is notable that the land opportunity cost (o) from the standardized equation (Equation 10) was omitted from the cost analysis due to data resource constraints.

4.2.1 Installation Costs

4.2.1.1 Installation Costs of Tree Cover

Based on the data from Green Analytics (2019) regarding the cost of trees and the number of trees planted per hectare on average over a ten-year period (see Table 3), it is estimated that the average cost is \$603,555.48 per square kilometre of tree installation.

4.2.1.1.1 Moderate Scenario

Based on the information about neighbourhood size and coverage in the report from Dardir and colleagues (2023), it is estimated that the moderate coverage scenario (increasing from 35.7% to 58.8% TC) requires an additional coverage of approximately 0.95 km² at the neighbourhood level. The estimated cost of installation for TC at the neighbourhood level in this scenario is \$573,377.71. If this is then applied to the entire region, with a total land area of 1758.27 km², the total regional cost is estimated at \$245,140,317.07 for the moderate coverage scenario of TC.

4.2.1.1.2 Intense Scenario

Based on the information about neighbourhood size and coverage in the report from Dardir and colleagues (2023), it is estimated that the intense coverage scenario (increasing from 35.7% to 81.8% TC) requires an additional coverage of approximately 1.9 km² at the neighbourhood level. The estimated cost of installation for TC in this scenario is \$1,146,755.41. If this is then applied to the entire region, with a total land area of 1758.27 km², the total regional cost is estimated at \$489,219,421.65 for the intense coverage scenario of TC.

4.2.1.2 Installation Costs of Ground Vegetation Cover

Below are the estimated installation costs for the scenarios, using the estimated GVC costs per unit (square meter) is \$330.39, plus a base rate of \$3793.20 per project.

4.2.1.2.1 Moderate Scenario

Based on the information about neighbourhood size and coverage in the report from Dardir and colleagues (2023), it is estimated that the moderate coverage scenario (increasing from 35.7% to 58.8% GC) requires an additional coverage of approximately 0.95 km². If we assume that the entire increased GC area will contain GVC (for example, GVC such as grass, flowers, and shrubs that

surround the trees) in addition to TC, the estimated cost of installation for GVC in this scenario is approximately \$313.9 million at the neighbourhood level and \$133.9 billion at the regional level.

4.2.1.2.2 Intense Scenario

Based on the information about neighbourhood size and coverage in the report from Dardir and colleagues (2023), it is estimated that the moderate coverage scenario (increasing from 35.7% to 81.8% GC) requires an additional coverage of approximately 1.9 km². If we assume that the entire increased GC area will contain GVC (for example, GVC such as grass, flowers, and shrubs that surround the trees) in addition to TC, the estimated cost of installation for GVC in this scenario is approximately \$627.7 million at the neighbourhood level and \$267.9 billion at the regional level.

4.2.2 Maintenance Costs

Based on the York Region's budgeting data, the annual maintenance cost of tree boulevard planters and landscaped centre medians varies based on location factors (York Region, 2024a). In order to estimate maintenance costs for the region, an average annual maintenance cost of \$67,000 per square kilometre was obtained.

4.2.2.1 Moderate Scenario

Annual maintenance costs in the moderate scenario, with neighbourhood coverage expanding by approximately 0.95 km² are estimated to cost CAD \$63,650 annually. If expanded to the entire region, this maintenance cost would grow to approximately \$27.2 million annually.

4.2.2.2 Intense Scenario

Annual maintenance costs in the intense coverage scenario, with neighbourhood coverage expanding by approximately 1.9 km² are estimated to cost CAD \$130,650 annually. If expanded to the entire region, this maintenance cost would grow to approximately \$54.3 million annually.

4.2.3 Total Costs

Total costs equal installation costs of both TC and GVC, plus maintenance costs, with opportunity costs omitted (see Equation 10). At the regional level, the total base cost, including initial investments and maintenance in year one, is estimated at \$134.2 billion for the moderate scenario and \$268.4 billion for the intense scenario (see Table 6).

Table 6: Cost Estimates

Table 6 shows the cost components and values for both moderate and intense GC scenarios. Values are presented in 2025 CAD.

Cost Category	Description	Moderate GC Scenario	Intense GC Scenario
TC Installation (Cs)	One-time initial cost required to install tree cover	-\$245,140,317.07	-\$489,219,421.65
GVC Installation (Vs)	One-time initial cost required to install ground vegetation cover	-\$133,953,325,393.20	-\$267,868,605,888.60
Annual Maintenance (m)	Annual expense to maintain greenery cover	-\$27,164,480.00	-\$54,321,245.62
Total	Year one investment and maintenance total	-\$134,225,630,190.27	-\$268,412,146,555.87

4.3 Results of Cost-Benefit Analysis

All costs and benefits were calculated in the year 2025, using this as an establishment date. Based on an expected project life of 40 years, the full expected costs and benefits are projected until the year 2064. The NPV of the moderate scenario is approximately -\$129 billion, whereas the intense scenario provides a NPV of approximately -\$259 billion. Additionally, a BCR of approximately 0.01 was returned for both scenarios (see Table 7 for details). Tables detailing annual present values for costs and benefits for both scenarios, as well as annual cash flow, are available in Appendix A (Table 9 and Table 10).

Table 7: Cost-Benefit Analysis Results

Table 7 shows a summary of metrics from the cost-benefit analysis. All values presented are in 2025 CAD.

Metric	Moderate GC	Intense GC
Net Present Value	-\$129,293,200,870.47	-\$259,383,463,948.32
Benefit Cost Ratio	0.01	0.01
Present Value of Costs	-\$130,917,673,295.24	-\$261,797,201,176.98
Present Value of Benefits	\$1,624,472,424.78	\$2,413,737,228.66

Chapter 5: Discussion & Conclusion

5.1 Introduction

This study aimed to establish an economic valuation model for GC scenario outcomes that can be used to aid in decision-making regarding NbS for heat mitigation strategies. The proposed valuation model was tested in a case study of York Region, assessing intense and moderate GC scenarios to answer the following research questions:

(1) How do the variations in GC scenarios impact the economic valuation of nature-based urban development in the case study of York Region? (2) What are the costs associated with installing and maintaining GC scenarios? (3) Do the direct and indirect economic benefits of GC scenarios outweigh the costs of installation and maintenance?

This chapter will summarize key findings and interpret the results in relation to the questions and existing research. This will be broken down into sections based on the research questions. The discussion will then be followed by concluding comments and suggestions for future research.

5.2 Impact of Variations in GC Scenarios on Economic Valuation of NbS

The results highlight some key findings in relation to the impact of variations in GC scenarios on the economic valuation of nature-based urban development solutions to address heat mitigation and the urban heat island effect in York Region. Firstly, the results suggest that the type and magnitude of benefits can change depending on the spatial scale. For example, the results of biodiversity benefits, utilizing the pollination services value. This service was projected to provide more benefits in the moderate coverage scenario as compared to intense coverage. This resulted in projected annual benefit estimates of approximately \$61 million and \$24 million for moderate and intense coverage, respectively. Showing that not all benefits increase with expanding the greenery coverage area. Other benefit types generally increased in magnitude as spatial scale increased, with the exception of mental well-being benefits remaining constant. However, the benefits did not increase in magnitude directly with spatial scale. For example, the predicted reduction in all-cause emergency department visits resulted in estimated avoided costs of approximately \$45 thousand and \$126 thousand respectively.

Overall, the intense scenario was estimated to provide approximately 1.5 times more benefits than the moderate scenario, with an intense coverage scenario requiring land coverage that is approximately two times more than the moderate scenario. The results indicate that some benefits may not be dependent on spatial scale, may not scale proportionately with spatial scale, or may have an inverse relationship with spatial scale. In contrast, cost results directly increased in magnitude with coverage intensity. The costs of the intense scenario were exactly two times higher than the moderate scenario, as the cost categories were all dependent on spatial scale. These results suggest that spatial scale of GC scenarios can impact both the type and magnitude of benefits, but only the magnitude of costs.

The results surrounding spatial scale impacts on benefits and costs are mainly consistent with known examples of CBA of other NbSs, but there are some new insights. Raymond and colleagues (2017) recognized that some benefits can only be realized at specific spatial scales. However, it is not noted in any known valuation or CBA studies that there has been an inverse relationship with scale and benefits, as was found with the pollination service benefits provided by bees. A suggested reasoning for this inverse relationship is that bees may, in fact, benefit from heterogeneous landscapes and medium level urbanization, as this showed the greatest abundance in bee sampling (Brasil et al., 2023). The lack of valuation of benefit type changing with spatial scale in previous literature could be due to a lack of factors in the equations. For example, in the Rouge Park valuation study where bee pollination services were included, the function simply multiplied the value of crop production by the global average of crop production dependent on insect pollination (S. Wilson, 2012). It did not include factors considering bee abundance in relation to the scenario or the percentage of pollination requiring bees. Additionally, many previous studies did not include indirect co-benefits, including biodiversity indicators (Chelli et al., 2025). In contrast, it is agreed that costs vary with the scale of installation of NbS (Chelli et al., 2025). Cost variations can be due to factors such as economies of scale when considering the scale of installation (Chelli et al., 2025; Panduro et al., 2024). Literature review of CBA assessing NbS found that many studies were conducted at the site and neighbourhood level. It has been suggested that research be expanded to explore spatial influence at larger scales and to compare scales of installation (Chelli et al., 2025). By including analysis of both a smaller scale (moderate) and larger scale (intense) scenarios and applying them at the regional level to extract cost and benefit values, evidence on the installation impacts of larger interventions compared to smaller

ones was achieved. These results can be used to help inform planners and policymakers about the influence of the spatial scale of NbSs on benefits and costs.

The integration of a non-linear tree canopy scaling factor into the economic valuation framework, based on canopy growth data, represents a significant methodological advancement over traditional linear models. By acknowledging that the ES benefits of urban greenery – such as health benefits related to cooling and air quality improvements - do not emerge at a constant rate, the analysis more accurately captures the maturation process of urban forests. Early in the project lifespan, the benefits are understandably lower, as the trees have not yet fully grown. One exception to this rule was the mental well-being benefit, which was not stated in the literature to vary with the growth or size of GC and canopy cover; therefore, this benefit value remained constant throughout the project lifespan. In contrast, as time progresses, other benefit values increase to reflect canopy cover growth. This non-linear growth, modeled through a function like the tree canopy scaling factor, reflects empirical findings that mature trees provide dramatically higher returns in both direct and indirect services. The adoption of such a scaling function not only strengthens the theoretical underpinnings of the CBA but also supports more realistic projections of long-term economic outcomes.

5.3 Costs Associated with GC Scenarios

Key findings regarding the costs of GC scenarios included installation and maintenance costs. Firstly, the largest cost associated with both the moderate and intense scenarios was the installation cost of GVC. While all costs did increase with the spatial scale of the scenarios, it is notable just how large this cost was (over 500 times larger than the second-largest cost associated with the scenarios). Variation in literature values found for installation costs associated with TC versus GVC, which were then used in the calculation of cost values for both scenarios, resulted in a substantial cost difference. TC costs were estimated at \$603,555.48 per square kilometre, whereas GVC installation costs were quite large at over \$330 million per square kilometre. As the two aforementioned costs (GVC installation and TC installation) are all part of the initial investment costs, these costs were projected to be very high for both GC scenarios (approximately \$134 billion and \$268 billion, respectively) at the regional level. Yearly maintenance costs were estimated to be steady throughout the lifespan of the projects (40 years), and to include services such as watering, pruning, and weeding. These costs were based on regional budgeting data, and baseline estimates were approximately \$27 million and

\$54 million annually for moderate and intense coverage scenarios, respectively, at the regional level. Unlike benefits, costs did rise in magnitude, directly associated with the spatial scale of the scenarios. Intense coverage scenario costs were twice as high as moderate coverage scenario costs.

A major cost consideration is the land opportunity cost. This has previously been omitted from most CBA of NbS (Chelli et al., 2025; Panduro et al., 2024). A reason for the inclusion of this cost is to consider the full range of costs and potential losses the region may incur by implementing GC scenarios. It is suggested in government guidelines that opportunity cost be included in CBA, as data permits (Secretariat, 2018, 2019). Even though it is acknowledged as an indirect cost in literature, it is often not included in the cost calculation due to data constraints. A reason for not quantifying this cost is due to a lack of data for value transfer, and difficulty in estimating these values (Panduro et al., 2024). Similarly, it was also omitted from this study due to data constraints.

Costs of installation can vary greatly depending on factors such as labour costs and economy of scale (Chelli et al., 2025; Panduro et al., 2024). It is important to consider this when using a value transfer method, which has limitations of applicability to areas of similar location and socio-economic characteristics (Green Analytics, 2020). In a review and analysis of cost data, a wide range of estimates were found. However, a review study by Panduro and colleagues (2024) found an average installation cost for TC estimated at \$2496.62/tree, and an average installation cost for greenspace was estimated at \$110.68/m² when converted to current 2025 CAD values. Neither of these values aligns with the results found in this study. Tree costs were estimated to be substantially lower, while ground vegetation costs were estimated to be substantially higher (see Table 3 and Table 4 for more details on these costs). The data used for the calculation of installation costs in this study, derived from Green Analytics (2019) (for TC) and TRCA (2018) (for GVC), were both from reputable sources in Southern Ontario. As such, there should have been no discrepancies due to geography or socio-economic characteristics. However, the two costs of installation (TC and GVC) coming from Green Analytics (2019) and TRCA (2018) were substantially different in terms of their estimated values when compared to each other and literature values. The modest TC installation costs reported by Green Analytics (2019) were said to include total expenditure for tree planting activities, including labour, material, equipment, site preparation, and administrative overhead costs. Similarly, the GVC installation costs extracted from TRCA data included costs of equipment, labour, vegetation, and administrative costs (TRCA, 2018). One area that may have differed, resulting in some cost variation, could be the costs of excavation and hauling, which were not explicitly stated in the costs of site

preparation included in the PDA estimates averages by Green Analytics (2019). Additionally, the TC installation costs were based on a number of trees planted per square kilometre using historical data. This number could also vary depending on project planning and scenario type. These results indicate that considering factors such as scale, number of trees, and type of GC are all critical in the cost assessment of installation.

Maintenance costs have also shown that even within the region itself, there is variation in costs. For example, location factors can determine whether manual watering or water trucks are required for the maintenance of GC (York Region, 2024a). This caused a great deal of variation in the literature values of cost estimates for standard care of street trees, landscaped medians, and boulevards. In York Region itself, this cost can vary from \$2,000 to \$131,000 per kilometre (York Region, 2024a). In the analysis, an average of these values was used to estimate maintenance costs for the region. However, a more accurate estimation may have been made if the exact locations of the proposed GC scenarios were established. These maintenance costs are low compared to the literature, where a mean maintenance value of urban greenspace is approximately 1.79 EUR per square metre (Panduro et al., 2024). This is equivalent to a mean maintenance cost of \$3.30 CAD 2025 and a maximum maintenance cost of \$23.03 CAD 2025 per square metre. Even this maximum maintenance cost found in literature is lower than the estimated maintenance cost based on York Region budget data, which was estimated to be \$28.59 per square metre (2025 CAD). However, it is projected that these costs will reduce further as the region reduces unneeded watering through soil moisture monitoring sensors. This is based on a pilot project, which has not yet been implemented throughout the region (York Region, 2024a). Therefore, reduced maintenance costs cannot yet be estimated.

5.4 Do the Benefits of GC Scenarios Outweigh the Costs?

Key findings in the CBA of the scenarios showed that the direct and indirect benefits of each scenario do not outweigh the associated costs. Both scenarios returned negative NPV, which indicated that costs outweigh benefits over the project lifespan. In the initial year of project implementation, costs will significantly outweigh the estimated benefits. However, when assessed annually, it is seen that benefits will outweigh costs for both scenarios. In year 12 (2036), it was seen that annual benefits outweighed annual costs. In contrast, the intense scenario annual benefits did not outweigh annual costs until year 15 (2039) (see Table 9 and Table 10 for detailed annual values). To better assess economic viability over the lifespan, two criteria were utilised. First, the NPV was assessed. Both

coverage scenarios returned negative NPVs (approximately -\$129 billion and -\$259 billion for moderate and intense scenarios, respectively). Next, BCR was assessed. Both scenarios returned a BCR with values of approximately 0.01. Both metrics indicate that costs outweigh project benefits during the 40-year life span of the assessment.

In contrast, it is found in the literature review that most CBAs of NbS return positive results for NPV (Chelli et al., 2025). One reason for the difference in results is the inclusion of the tree canopy scaling factor. Rather than benefits being stable over time, the results show that benefits are assumed to increase non-linearly with tree maturity – the early years of a project appear less advantageous, while the later years reveal a robust cumulative impact. While this is recognized in literature, it has not been included in traditional CBA studies of NbS, with few exceptions (Chelli et al., 2025). One exception is the tree value analysis provided by McPherson (2007), which showed scaling of benefits with tree growth. This 2007 study also returned a negative NPV for scenarios when using a benefit-based approach similar to the CBA performed in this thesis (McPherson, 2007). Both studies highlight the growth of benefits over time as trees mature, emphasizing the long-term benefits of trees and how scaling benefits with tree growth can impact NPV.

It is suggested that most long-term benefits are not realized in urban tree planting due to early felling of trees (Barrell, 2018; Natural Capital Investment: Urban Forest Canopy Benefits, 2022). For example, it is suggested that most urban trees have life expectancies of 150-300 years, and that if trees are felled before 50 years, 85-90% of benefits could be lost (Barrell, 2018). Therefore, by only assessing over a 40-year life expectancy, it is possible that benefits have not yet reached peak return and that up to 260 years of benefit delivery could be unaccounted for. Using a similar methodology to that used in conventional forest management to determine optimal timber rotation length to maximize timber product volume, Barrel Tree Consultancy (2018) suggests that optimal rotation in urban planting of long-lived trees in urban areas is 270 years to achieve maximum benefit realization. This theory, along with the evidence of this study and the benefit-based approach study by McPherson (2007), underscores the importance of adopting a long-term perspective when evaluating nature-based solutions in urban settings.

Another reason why other CBA results of NbS return positive results may be due to the inclusion of differing benefit categories. For example, this thesis was unable to include the value of aesthetics, stormwater runoff reductions, or sequestration of carbon dioxide. These additional benefits

may have helped to improve the NPV and BCR results, despite the high investment costs of the proposed scenarios. For instance, aesthetic value – based on property sales in areas with and without trees – was seen as the largest benefit category by annual value (over \$100 per tree) followed by reduction in stormwater runoff in a study valuing urban trees by McPherson (2007). Similarly, the economic valuation of tree planting in Ontario by Green Analytics (2019) also included the categories of aesthetics and water supply regulation, valued at \$4,149 and \$1,884 per hectare annually, respectively, in urban settings. Carbon sequestration is another benefit often included in other studies that was unable to be included in this study. In a review study of urban park benefits, 5 out of 11 studies that were focused on air quality included carbon sequestration modelling or on-site measurements (Konijnendijk et al., 2013). Another review study of economic evaluations of urban green and blue space interventions found that 10 out of 43 studies included the analysis of carbon sequestration (Tate et al., 2024). One study demonstrated a value of carbon sequestration in a US city averaging \$5.25/tree/year in 2006 (McPherson et al., 2006). In a Canadian study valuing ES in Ontario's Greenbelt, it was estimated that grasslands provide a value of \$29/hectare/year (2008\$CA) in carbon uptake (S. Wilson, 2008), while a study of the city trees in Toronto estimated 46,700 metric tons of carbon removal per year, valued at \$1.1 million (2013\$CA) annually (Nowak et al., 2013). Together, it can be said that these, along with other possible benefits that were unable to be included in this thesis, may impact the results of both NPV and BCR.

The rule of NPV for decision making is to adopt projects with a positive NPV and rank them by their NPV (OECD, 2006). Based on this alone, it can be said that neither scenario is economically viable; however, the moderate coverage scenario would be ranked higher, with a higher NPV, and should therefore be the one to be adopted if one were to be chosen over the other. That said, the results do indicate a growing value over time, with benefits that do not end at 40 years if the GC is still maintained. As stated in a previous CBA on NbS that returned negative results, “Although the net present value is negative, the benefits may continue to accumulate” (Hsu & Chao, 2020, p. 4). This is also in alignment with the research and theory from Barrel Tree Consultancy, emphasizing that optimal benefit rotation length may be up to 270 years (Barrell, 2018). These studies suggest that there is long-term value to the projects, both economically and in terms of sustainable development.

Similarly to NPV, it is a general rule to accept projects with a BCR greater than 1, or select the project with the highest BCR when choosing between mutually exclusive project options (OECD, 2006). It is also noted that BCR is greatly influenced by scale, and “more benefits per dollar spent

will appear to be preferred to a regulation with larger total net benefits but with lower benefit per dollar spent” (Secretariat, 2019, p. 36). As neither project returned a BCR above 1, and both were approximately the same value of 0.01, neither can be prioritized by this metric. However, decision-making is best rationalized using the NPV results (OECD, 2006; Secretariat, 2019). Therefore, it is suggested that the moderate coverage scenario would be adopted if faced with a mutually exclusive choice. The results indicate that neither project is economically suitable for implementation.

However, results showing such large differences between NPV and BCR are enlightening and show the influence of benefit realization being scaled with tree growth, discounting, and large initial investments. This is often not considered and has not been seen in previous studies of the economic viability of NbS.

5.5 Limitations and Suggestions for Future Research

The economic model comes with limitations that must be considered. Firstly, the transfer methodology of costs and benefits is not known with certainty. Therefore, risk (probabilistic outcomes) and uncertainty (when no probabilities are known) should be taken into account (OECD, 2006). Valuation methodologies and estimation frameworks were developed using established approaches to ensure replicability; however, reliability could be enhanced through sensitivity analysis of key variables. Particularly, an analysis of the impact of discounting is recommended (Secretariat, 2019). Due to time constraints, this was not able to be included. Furthermore, the model could be strengthened with the inclusion of more benefit categories – such as carbon sequestration, flood mitigation, and aesthetic value – as well as cost data from regional budgets. Due to data resource limitations, this was unable to be expanded on.

It is suggested that future research focus on incorporating species data for TC and GVC installation that is region or project-specific into the assessment of installation costs and tree canopy growth factor. This would provide a more precise understanding of how canopy expansion influences benefit realization and the CBA, providing a deeper understanding to facilitate more nuanced results as well as provide more accurate installation cost estimates. Another potential inclusion in the analysis could be expanding the life expectancy or comparing multiple life expectancies to better demonstrate the long-term value of tree cover. It is also recommended that future research explores further inclusion of benefits where data permits, to ensure a fulsome economic model. Finally, utilizing Monte Carlo analysis is recommended by both Canadian and US government organizations

to yield a more accurate assessment of costs and benefits (Guiding Principles for Monte Carlo Analysis, 1997; Secretariat, 2019).

5.6 Conclusion

Key findings included the influence of spatial scale on the benefits, where both the magnitude and type of benefits can be influenced by the spatial scale of the project. Additionally, it was found that costs grew in magnitude proportional to the spatial scale. Another key finding was the influence of tree canopy growth on the temporal scale of benefit accumulation, suggesting that benefits are not all realized at the initial onset of the project, but grow over time with canopy coverage maturation. Additionally, it was found that not all benefits scale with tree canopy growth, for example, mental well-being. It is also noted that NPV and BCR values were below the threshold of suggested implementation for both scenarios, showing that benefits do not outweigh costs during the life of the projects investigated. If necessary to rank them or decide between mutually exclusive scenarios, the moderate coverage scenario resulted in a higher NPV. However, both scenarios require substantial initial investments, which, along with discounting and benefits scaled with canopy growth, result in a BCR below one. All things considered, neither project would be considered economically suitable when considered over a 40-year life span.

Despite the limitations of the CBA utilizing benefit transfer and avoided cost methods, the economic framework still aids in expanding the current research in this area. Quantitative research is foundational to evidence-based decision making, and it provides empirical rigor that enables academics, practitioners, and policymakers to derive actionable insights. Its role can be seen as a necessity in ensuring academic credibility and real-world applicability (W. M. Lim, 2024). Since the goal was to provide an economic valuation model for outcomes that can support decision-making for urban upgrading plans associated with GC heat mitigation strategies and NbSs, providing empirical evidence is crucial. Furthermore, by including a broader range of direct and indirect benefits and costs, and scaling benefits to incorporate the influence of tree canopy growth, a more holistic framework and approach to CBA of NbS has been developed and tested in the case study of York Region. Thus, this research contributes to knowledge on the economic costs and benefits of GC scenarios in a major Canadian city, while also advancing research knowledge on the economic assessment of costs and benefits over time with the novel CBA approach developed. Fundamentally,

this study integrates scholarly analysis with real-world policy considerations to facilitate a holistic evaluation that supports the development of sustainable urban planning approaches.

References

- Aghamohammadi, N. (with Santamouris, M.). (2022). *Urban Overheating: Heat Mitigation and the Impact on Health* (1st ed). Springer.
- Alcon, F., Pedrero, F., Martin-Ortega, J., Arcas, N., Alarcon, J. J., & Miguel, M. D. de. (2010). The non-market value of reclaimed wastewater for use in agriculture: A contingent valuation approach. *Spanish Journal of Agricultural Research*, 8, 187–196.
<https://doi.org/10.5424/sjar/201008S2-1361>
- Anderson, V., & Gough, W. A. (2020). Evaluating the potential of nature-based solutions to reduce ozone, nitrogen dioxide, and carbon dioxide through a multi-type green infrastructure study in Ontario, Canada. *City and Environment Interactions*, 6, 100043.
<https://doi.org/10.1016/j.cacint.2020.100043>
- Arrow, K. J., & Kruz, M. (2013). *Public investment, the rate of return, and optimal fiscal policy*. RFF Press.
- Ballester, J., Quijal-Zamorano, M., Méndez Turrubiates, R. F., Pegenaute, F., Herrmann, F. R., Robine, J. M., Basagaña, X., Tonne, C., Antó, J. M., & Achebak, H. (2023). Heat-related mortality in Europe during the summer of 2022. *Nature Medicine*, 29(7), 1857–1866.
<https://doi.org/10.1038/s41591-023-02419-z>
- Bank of Canada. (n.d.). *Inflation Calculator*. Retrieved April 4, 2025, from
<https://www.bankofcanada.ca/rates/related/inflation-calculator/>
- Barrell, J. (2018). *Tree Value; the Missing Metric in Built-Environment Management*. Barrell Tree Consultancy. <https://www.barrelltreecare.co.uk/assets/Uploads/BTC-125-2018-Ecobuild.pdf>

- Basagaña, X., Sartini, C., Barrera-Gómez, J., Dadvand, P., Cunillera, J., Ostro, B., Sunyer, J., & Medina-Ramón, M. (2011). Heat Waves and Cause-specific Mortality at all Ages. *Epidemiology*, 22(6), 765–772. <https://doi.org/10.1097/EDE.0b013e31823031c5>
- Berardi, U., Jandaghian, Z., & Graham, J. (2020). Effects of greenery enhancements for the resilience to heat waves: A comparison of analysis performed through mesoscale (WRF) and microscale (Envi-met) modeling. *Science of The Total Environment*, 747, 141300. <https://doi.org/10.1016/j.scitotenv.2020.141300>
- Biasin, A., Masiero, M., Amato, G., & Pettenella, D. (2023). Nature-Based Solutions Modeling and Cost-Benefit Analysis to Face Climate Change Risks in an Urban Area: The Case of Turin (Italy). *Land*, 12(2), Article 2. <https://doi.org/10.3390/land12020280>
- Brasil, S. N. R., Ayers, A. C., & Rehan, S. M. (2023). The effect of urbanisation and seasonality on wild bee abundance, body size and foraging efforts. *Ecological Entomology*, 48(4), 499–507. <https://doi.org/10.1111/een.13243>
- Brouwer, R., & Pearce, D. W. (Eds.). (2005). *Cost-benefit analysis and water resources management*. Edward Elgar.
- Burton, A., & Wickerson, G. (2025). Economic Impacts of Extreme Heat: Energy. *Federation of American Scientists*. <https://fas.org/publication/economic-impacts-of-extreme-heat-energy/>
- Canada, E. and CC. (2011). *Historical Climate Data—Climate—Environment and Climate Change Canada*. <https://climate.weather.gc.ca/>
- Canadian Climate Institute. (2022). *Damage Control: Reducing the costs of climate impacts in Canada*. https://climateinstitute.ca/wp-content/uploads/2022/09/Damage-Control_-EN_0927.pdf
- Canadian Institute for Climate Choices. (2021). *THE HEALTH COSTS OF CLIMATE CHANGE*. <https://climateinstitute.ca/reports/the-health-costs-of-climate-change/>

- Chagnon, M., Gingras, J., & DeOliveira, D. (1993). Complementary Aspects of Strawberry Pollination by Honey and IndigenQus Bees (Hymenoptera). *Journal of Economic Entomology*, 86(2), 416–420. <https://doi.org/10.1093/jee/86.2.416>
- Chelli, A., Brander, L., & Geneletti, D. (2025). Cost-Benefit analysis of urban nature-based solutions: A systematic review of approaches and scales with a focus on benefit valuation. *Ecosystem Services*, 71, 101684. <https://doi.org/10.1016/j.ecoser.2024.101684>
- Chestnut, L. G., & Civita, P. D. (2009). *Economic Valuation of Mortality Risk Reduction: Review and Recommendations for Policy and Regulatory Analysis*.
https://publications.gc.ca/collections/collection_2009/policyresearch/PH4-51-2009E.pdf
- CIHI. (2022a). *Canadian Management Information System Database metadata*.
<https://www.cihi.ca/en/canadian-management-information-system-database-metadata>
- CIHI. (2022b). *Trends in Hospital Spending*.
- Colacito, R., Hoffmann, B., & Phan, T. (2019). Temperature and Growth: A Panel Analysis of the United States. *Journal of Money, Credit and Banking*, 51(2–3), 313–368.
<https://doi.org/10.1111/jmcb.12574>
- Costanza, R., Kubiszewski, I., Stoeckl, N., & Kompas, T. (2021). Pluralistic discounting recognizing different capital contributions: An example estimating the net present value of global ecosystem services. *Ecological Economics*, 183, 106961.
<https://doi.org/10.1016/j.ecolecon.2021.106961>
- Coumou, D., & Robinson, A. (2013). Historic and future increase in the global land area affected by monthly heat extremes. *Environmental Research Letters*, 8(3), 034018.
<https://doi.org/10.1088/1748-9326/8/3/034018>

Creswell, J. W., & Creswell, J. D. (2018). *Research Design: Qualitative, Quantitative, and Mixed Methods Approaches*. SAGE Publications.

<https://books.google.ca/books?id=s4ViswEACAAJ>

Dardir, M., & Berardi, U. (2021). Development of microclimate modeling for enhancing neighborhood thermal performance through urban greenery cover. *Energy and Buildings*, 252, 111428. <https://doi.org/10.1016/j.enbuild.2021.111428>

Dardir, M., Umberto, B., & Wilson, J. (2023). Health-informed predictive regression for statistical-simulation decision-making in urban heat mitigation. *Sustainable Cities and Society*, 98, 104853. <https://doi.org/10.1016/j.scs.2023.104853>

Dardir, M., Wilson, J., & Berardi, U. (2023). Heat and air quality related cause-based elderly mortalities and emergency visits. *Environmental Research*, 216, 114640. <https://doi.org/10.1016/j.envres.2022.114640>

Deilami, K., Kamruzzaman, Md., & Liu, Y. (2018). Urban heat island effect: A systematic review of spatio-temporal factors, data, methods, and mitigation measures. *International Journal of Applied Earth Observation and Geoinformation*, 67, 30–42. <https://doi.org/10.1016/j.jag.2017.12.009>

del Saz Salazar, S., & Menendez, L. G. (2007). Estimating the non-market benefits of an urban park: Does proximity matter? *Land Use Policy*, 24(1), 296–305.

Ebi, K. L., Capon, A., Berry, P., Broderick, C., De Dear, R., Havenith, G., Honda, Y., Kovats, R. S., Ma, W., Malik, A., Morris, N. B., Nybo, L., Seneviratne, S. I., Vanos, J., & Jay, O. (2021). Hot weather and heat extremes: Health risks. *The Lancet*, 398(10301), 698–708. [https://doi.org/10.1016/S0140-6736\(21\)01208-3](https://doi.org/10.1016/S0140-6736(21)01208-3)

- Environment and Climate Change Canada. (2022a). *Adapting to Climate Change in Canada*.
<https://www.canada.ca/en/environment-climate-change/services/climate-change/adapting.html>
- Environment and Climate Change Canada. (2022b, November 24). *National Adaptation Strategy for Canada*. <https://www.canada.ca/en/services/environment/weather/climatechange/climate-plan/national-adaptation-strategy/full-strategy.html>
- Environment and Climate Change Canada. (2024). *National Adaptation Strategy*.
<https://www.canada.ca/en/services/environment/weather/climatechange/climate-plan/national-adaptation-strategy.html>
- Environment and Climate Change Canada. (2025). *Historical Data—Climate*.
https://climate.weather.gc.ca/historical_data/search_historic_data_e.html
- European Commission. (2024, October 17). *Nature-based solutions*. https://research-and-innovation.ec.europa.eu/research-area/environment/nature-based-solutions_en
- European Environment Agency. (n.d.). *Over 61,000 excess deaths quantified in Europe due to heat in record summer 2022*. Retrieved February 19, 2025, from <https://climate-adapt.eea.europa.eu/en/observatory/news-archive-observatory/over-61-000-excess-deaths-in-europe-due-to-heat-in-record-summer-2022>
- Fu, J., Dupre, K., Tavares, S., King, D., & Banhalimi-Zakar, Z. (2022). Optimized greenery configuration to mitigate urban heat: A decade systematic review. *Frontiers of Architectural Research*, 11(3), 466–491. <https://doi.org/10.1016/j.foar.2021.12.005>
- García De Jalón, S., Chiabai, A., Mc Tague, A., Artaza, N., De Ayala, A., Quiroga, S., Kruize, H., Suárez, C., Bell, R., & Taylor, T. (2020). Providing Access to Urban Green Spaces: A Participatory Benefit-Cost Analysis in Spain. *International Journal of Environmental Research and Public Health*, 17(8), 2818. <https://doi.org/10.3390/ijerph17082818>

Gerner, E. (2020). *The effects of impervious surface area, tree canopy cover, and floral richness on bee abundance, richness, and diversity across an urban landscape.*

Government of Canada. (2018). *Thermal stress in the work place.*

<https://publications.gc.ca/site/eng/9.863663/publication.html>

Government of Canada. (2019). *Canada's changing climate report.* Environment and Climate Change Canada.

https://changingclimate.ca/site/assets/uploads/sites/2/2020/06/CCCR_FULLREPORT-EN-FINAL.pdf

Government of Canada. (2021, June 2). *Natural Climate Solutions.*

<https://www.canada.ca/en/campaign/natural-climate-solutions.html>

Government of Ontario. (2024). *Labour market report, January 2024.*

<http://www.ontario.ca/page/labour-market-report-january-2024>

Grace, M., Balzan, M., Collier, M., Geneletti, D., Tomaskinova, J., Abela, R., Borg, D., Buhagiar, G., Camilleri, L., Cardona, M., Cassar, N., Cassar, R., Cattafi, I., Cauchi, D., Galea, C., La Rosa, D., Malekkidou, E., Masini, M., Portelli, P., ... Dicks, L. V. (2021). Priority knowledge needs for implementing nature-based solutions in the Mediterranean islands. *Environmental Science and Policy*, 116, 56–68. Scopus. <https://doi.org/10.1016/j.envsci.2020.10.003>

Green Analytics. (2019). *The Economic Value of Tree Planting in Southern Ontario.*

<https://assets.ctfassets.net/e09p19lzfefe/5jKhAS5bxOeuljxTL7fOzg/fc2983b8003ce0b2eff37bdaa2dca91c/Green-Analytics-Report-The-Economic-Value-of-Tree-Planting-in-Southern...-1.pdf>

Green Analytics. (2020). *A Conceptual Framework to Understand the Business Case for EcoHealth in Ontario.*

- https://static1.squarespace.com/static/5c3cebfd45776eee4408f72d/t/5ecb445972e6a72aac117171/1590379619631/FO_8.5x11_EH_REPORT_FA_4WEB+%281%29.pdf
- Guiding Principles for Monte Carlo Analysis*. (1997). US Environmental Protection Agency.
- <https://www.epa.gov/sites/default/files/2014-11/documents/montecar.pdf>
- Hanley, N., & Spash, C. (1996). *Cost benefit analysis and the environment*.
- Harnik, P. (2009). *Measuring the economic value of a city park system*. Trust for Public Land.
- Harvard Law Review. (2015, November 10). *Michigan v. EPA*. Harvard Law Review.
- <https://harvardlawreview.org/print/vol-129/michigan-v-epa/>
- Hayes, A., Jandaghian, Z., Lacasse, M. A., Gaur, A., & Laouadi, A. (2022). *Nature based solutions to mitigate urban heat island effects in Canadian cities: Literature review*. National Research Council of Canada.
- Health Canada. (2021). *Health Impacts of Air Pollution in Canada 2021 Report* [Education and awareness]. <https://www.canada.ca/en/health-canada/services/publications/healthy-living/health-impacts-air-pollution-2021.html>
- Henderson, S. B., McLean, K. E., Lee, M. J., & Kosatsky, T. (2022). Analysis of community deaths during the catastrophic 2021 heat dome: Early evidence to inform the public health response during subsequent events in greater Vancouver, Canada. *Environmental Epidemiology*, 6(1), e189. <https://doi.org/10.1097/EE9.0000000000000189>
- Hengeveld, H., Whitewood, B., & Fergusson, A. (2005). *An introduction to climate change: A Canadian perspective*. Environment Canada.
- Horn, M. E. (2011). *A comparison of pollinator biodiversity between green spaces, industrial areas and residential land-use zones in urban, Southern Ontario*. Library and Archives Canada = Bibliothèque et Archives Canada.

- Hsu, K.-W., & Chao, J.-C. (2020). Economic Valuation of Green Infrastructure Investments in Urban Renewal: The Case of the Station District in Taichung, Taiwan. *Environments*, 7(8), Article 8. <https://doi.org/10.3390/environments7080056>
- Huang, Y. J., Akbari, H., & Taha, H. (1990). The Wind-Shielding and Shading Effects of Trees on Residential Heating and Cooling Requirements. *ASHRAE Proceedings*, 96(pt. 1). <https://escholarship.org/uc/item/85g3s8xt>
- Hutton, G., Rehfuss, E., & Organization, W. H. (2006). Guidelines for conducting cost-benefit analysis of household energy and health interventions. In *Guidelines for conducting cost-benefit analysis of household energy and health interventions/Guy Hutton with Eva Rehfuss*.
- Hystad, P., Payette, Y., Noisel, N., & Boileau, C. (2019). Green space associations with mental health and cognitive function: Results from the Quebec CARTaGENE cohort. *Environmental Epidemiology*, 3(1), e040. <https://doi.org/10.1097/EE9.0000000000000040>
- IPCC. (2014). *Climate change 2014: Mitigation of climate change: Working Group III contribution to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge University Press.
- IPCC. (2018). *Summary for Policymakers—Global Warming of 1.5 °C*. <https://www.ipcc.ch/sr15/chapter/spm/>
- IPCC. (2021). *Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge University Press. <https://doi.org/10.1017/9781009157896>
- IPCC. (2023). *AR6 Synthesis Report: Climate Change 2023 — IPCC*. <https://www.ipcc.ch/report/sixth-assessment-report-cycle/>
- IUCN. (2025, March 24). *Nature-based Solutions*. <https://iucn.org/our-work/nature-based-solutions>

- Klein, A.-M., Vaissière, B. E., Cane, J. H., Steffan-Dewenter, I., Cunningham, S. A., Kremen, C., & Tscharntke, T. (2006). Importance of pollinators in changing landscapes for world crops. *Proceedings of the Royal Society B: Biological Sciences*, 274(1608), 303–313.
<https://doi.org/10.1098/rspb.2006.3721>
- Klinenberg, E. (2015). *Heat Wave: A Social Autopsy of Disaster in Chicago*. University of Chicago Press.
- Kondo, M. C., Fluehr, J. M., McKeon, T., & Branas, C. C. (2018). Urban Green Space and Its Impact on Human Health. *International Journal of Environmental Research and Public Health*, 15(3), Article 3. <https://doi.org/10.3390/ijerph15030445>
- Konijnendijk, C., Annerstedt, M., Nielsen, A., & Maruthaveeran, S. (2013). *Benefits of Urban Parks A Systematic Review*. <https://www.theparksalliance.org/benefits-of-urban-parks-a-systematic-review-a-report-for-ifpra-published-in-january-2013/>
- Kula, E. (1994). Valuation methods for environmental costs and benefits. In E. Kula, *Economics of Natural Resources, the Environment and Policies* (pp. 234–255). Springer Netherlands.
https://doi.org/10.1007/978-94-011-6037-7_8
- Kurn, D. M., Bretz, S. E., Huang, B., & Akbari, H. (1994). *The potential for reducing urban air temperatures and energy consumption through vegetative cooling* (No. LBL-35320). Lawrence Berkeley National Lab. (LBNL), Berkeley, CA (United States).
<https://doi.org/10.2172/10180633>
- Lemmen, D. S. & Kanada (Eds.). (2004). *Climate change impacts and adaptation: A Canadian perspective*. Climate Change Impacts and Adaption Directorate, Natural Resources Canada.
- Levermore, G., Parkinson, J., Lee, K., Laycock, P., & Lindley, S. (2018). The increasing trend of the urban heat island intensity. *Urban Climate*, 24, 360–368.
<https://doi.org/10.1016/j.uclim.2017.02.004>

- Lim, K. L., Jacobs, P., Ohinmaa, A., Schopflocher, D., & Dewa, C. S. (2008). A new population-based measure of the economic burden of mental illness in Canada. *Chronic Diseases in Canada*, 28(3), 92–98. <https://doi.org/10.24095/hpcdp.28.3.02>
- Lim, W. M. (2024). What Is Quantitative Research? An Overview and Guidelines. *Australasian Marketing Journal*, 14413582241264622. <https://doi.org/10.1177/14413582241264622>
- Lind, R. C., Arrow, K. J., Corey, G. R., Dasgupta, P., Sen, A. K., Stauffer, T., Stiglitz, J. E., & Stockfish, J. A. (2013). *Discounting for time and risk in energy policy*. RFF Press.
- Liu, S., Costanza, R., Farber, S., & Troy, A. (2010). Valuing ecosystem services: Theory, practice, and the need for a transdisciplinary synthesis. *Annals of the New York Academy of Sciences*, 1185(1), 54–78. <https://doi.org/10.1111/j.1749-6632.2009.05167.x>
- Maas, J., Verheij, R. A., de Vries, S., Spreeuwenberg, P., Schellevis, F. G., & Groenewegen, P. P. (2009). Morbidity is related to a green living environment. *Journal of Epidemiology & Community Health*, 63(12), 967–973. <https://doi.org/10.1136/jech.2008.079038>
- Mahmoud, I. H., Morello, E., Lemes de Oliveira, F., Geneletti, D., Lemes de Oliveira, F., Geneletti, D., Mahmoud, I. H., & Morello, E. (2022). *Nature-Based Solutions for Sustainable Urban Planning: Greening Cities, Shaping Cities* (1st ed.). Springer International Publishing AG. <https://doi.org/10.1007/978-3-030-89525-9>
- McPherson, E. G. (2002). Green plants or power plants. *Center for Urban Forest Research*. Davis, CA.
- McPherson, E. G. (2007). Benefit-Based Tree Valuation. *Arboriculture & Urban Forestry (AUF)*, 33(1), 1–11. <https://doi.org/10.48044/jauf.2007.001>
- McPherson, E. G., Simpson, J. R., Peper, P. J., Maco, S. E., Gardner, S. L., Cozad, S. K., & Xiao, Q. (2006). Midwest community tree guide: Benefits, costs, and strategic planting. *Gen. Tech.*

- Rep. PSW-GTR-199. Albany, CA: U.S. Department of Agriculture, Forest Service, Pacific Southwest Research Station. 99 p, 199.* <https://doi.org/10.2737/PSW-GTR-199>
- Miner, M. J., Taylor, R. A., Jones, C., & Phelan, P. E. (2017). Efficiency, economics, and the urban heat island. *Environment & Urbanization*, 29(1), 183–194.
<https://doi.org/10.1177/0956247816655676>
- Moslehi, I., Jalili Ghazizadeh, M., & Yousefi-Khoshqalb, E. (2020). An economic valuation model for alternative pressure management schemes in water distribution networks. *Utilities Policy*, 67, 101129. <https://doi.org/10.1016/j.jup.2020.101129>
- Natural Capital Investment: Urban Forest Canopy Benefits.* (2022). University of Maryland School of Architecture, Planning & Preservation.
<https://search.umd.edu/#gsc.tab=0&gsc.q=site:arch.umd.edu%20natural%20capital%20investment&gsc.sort=>
- Nesshöver, C., Assmuth, T., Irvine, K. N., Rusch, G. M., Waylen, K. A., Delbaere, B., Haase, D., Jones-Walters, L., Keune, H., Kovacs, E., Krauze, K., Külvik, M., Rey, F., van Dijk, J., Vistad, O. I., Wilkinson, M. E., & Wittmer, H. (2017). The science, policy and practice of nature-based solutions: An interdisciplinary perspective. *Science of The Total Environment*, 579, 1215–1227. <https://doi.org/10.1016/j.scitotenv.2016.11.106>
- Nowak, D. J., Crane, D. E., & Stevens, J. C. (2006). Air pollution removal by urban trees and shrubs in the United States. *Urban Forestry & Urban Greening*, 4(3), 115–123.
<https://doi.org/10.1016/j.ufug.2006.01.007>
- Nowak, D. J., Hirabayashi, S., Doyle, M., McGovern, M., & Pasher, J. (2018). Air pollution removal by urban forests in Canada and its effect on air quality and human health. *Urban Forestry & Urban Greening*, 29, 40–48. <https://doi.org/10.1016/j.ufug.2017.10.019>

- Nowak, D. J., Hoehn, R. E. I., Bodine, A. R., Greenfield, E. J., Ellis, A., Endreny, T. A., Yang, Y., Zhou, T., & Henry, R. (2013). Assessing urban forest effects and values: Toronto's urban forest. *Resour. Bull. NRS-79. Newtown Square, PA: U.S. Department of Agriculture, Forest Service, Northern Research Station. 59 p., 79, 1–59.* <https://doi.org/10.2737/NRS-RB-79>
- OECD. (2006). *Cost-Benefit Analysis and the Environment: Recent Developments*. OECD Publishing. <https://doi.org/10.1787/9789264010055-en>
- OECD. (2011). *Valuing mortality risk reductions in regulatory analysis of environmental Health and Transport Policies: Policy Implications*. [https://one.oecd.org/document/ENV/EPOC/WPIEEP\(2011\)8/FINAL/en/pdf](https://one.oecd.org/document/ENV/EPOC/WPIEEP(2011)8/FINAL/en/pdf)
- Office of the Auditor General of Ontario. (2022). *Climate Change Adaptation: Reducing Urban Flood Risk*.
- Ontario Energy Board. (2024). *Electricity rates*. <https://www.oeb.ca/consumer-information-and-protection/electricity-rates#current>
- Panduro, T. E., Nainggolan, D., & Zandersen, M. (2024). Cost-effectiveness analysis of urban nature-based solutions: A stepwise ranking approach. *Nature-Based Solutions*, 6, 100186. <https://doi.org/10.1016/j.nbsj.2024.100186>
- Pearce, D. W., & Turner, R. K. (1989). *Economics of natural resources and the environment*. Johns Hopkins University Press.
- Peters, C. E., Ge, C. B., Hall, A. L., Davies, H. W., & Demers, P. A. (2015). CAREX Canada: An enhanced model for assessing occupational carcinogen exposure. *Occupational and Environmental Medicine*, 72(1), 64–71. <https://doi.org/10.1136/oemed-2014-102286>
- Privitera, R., & Ma, J. (2022). Planning Green Spaces Investments for Improving Health and Well-Being in Cities Through Valuing Urban Nature. In D. La Rosa & R. Privitera (Eds.),

- Innovation in Urban and Regional Planning* (pp. 38–46). Springer International Publishing.
https://doi.org/10.1007/978-3-030-96985-1_5
- Public Health Agency of Canada. (2017, November 8). *Public Health Agency of Canada 2016-2017 Departmental Results Reports* [Report on plans and priorities].
<https://www.canada.ca/en/public-health/corporate/transparency/corporate-management-reporting/departamental-performance-reports/2016-2017-departamental-results-report.html>
- Raymond, C. M., Frantzeskaki, N., Kabisch, N., Berry, P., Breil, M., Nita, M. R., Geneletti, D., & Calfapietra, C. (2017). A framework for assessing and implementing the co-benefits of nature-based solutions in urban areas. *Environmental Science & Policy*, 77, 15–24.
<https://doi.org/10.1016/j.envsci.2017.07.008>
- Rizwan, A. M., Dennis, L. Y. C., & Liu, C. (2008). A review on the generation, determination and mitigation of Urban Heat Island. *Journal of Environmental Sciences*, 20(1), 120–128.
[https://doi.org/10.1016/S1001-0742\(08\)60019-4](https://doi.org/10.1016/S1001-0742(08)60019-4)
- Rotenberg, M., Tuck, A., Anderson, K. K., & McKenzie, K. (2022). Green Space and the Incidence of Schizophrenia in Toronto, Canada. *The Canadian Journal of Psychiatry*, 67(3), 238–240.
<https://doi.org/10.1177/07067437221076722>
- Schwarz, K., Fragkias, M., Boone, C. G., Zhou, W., McHale, M., Grove, J. M., O’Neil-Dunne, J., McFadden, J. P., Buckley, G. L., Childers, D., Ogden, L., Pincetl, S., Pataki, D., Whitmer, A., & Cadenasso, M. L. (2015). Trees Grow on Money: Urban Tree Canopy Cover and Environmental Justice. *PLOS ONE*, 10(4), e0122051.
<https://doi.org/10.1371/journal.pone.0122051>
- Secretariat, T. B. of C. (2018, September 7). *Policy on Cost-Benefit Analysis*.
<https://www.canada.ca/en/government/system/laws/developing-improving-federal->

- regulations/requirements-developing-managing-reviewing-regulations/guidelines-tools/policy-cost-benefit-analysis.html
- Secretariat, T. B. of C. (2019). *Canada's Cost-Benefit Analysis Guide: Regulatory Proposals*.
https://view.officeapps.live.com/op/view.aspx?src=https%3A%2F%2Fwiki.gccollab.ca%2Fimages%2F8%2F8e%2FCBA_Guide-EN.doc&wdOrigin=BROWSELINK
- Seeds of Diversity. (2024). *Protecting Pollinators*. <https://seeds.ca/pollination/>
- Sheffield, P. E., Herrera, M. T., Kinnee, E. J., & Clougherty, J. E. (2018). Not so little differences: Variation in hot weather risk to young children in New York City. *Special Issue on Health and High Temperatures*, 161, 119–126. <https://doi.org/10.1016/j.puhe.2018.06.004>
- Stewart, I. D. (2019). Why should urban heat island researchers study history? *Urban Climate*, 30, 100484. <https://doi.org/10.1016/j.uclim.2019.100484>
- Stott, P. A., Stone, D. A., & Allen, M. R. (2004). Human contribution to the European heatwave of 2003. *Nature*, 432(7017), 610–614. <https://doi.org/10.1038/nature03089>
- Tate, C., Tran, N., Longo, A., Barry, J., Taylor, T., O'Neill, C., & Hunter, R. (2024). Economic evaluations of urban green and blue space interventions: A scoping review. *Ecological Economics*, 222, 108217. <https://doi.org/10.1016/j.ecolecon.2024.108217>
- Toronto Public Health. (2022). *Heat alerts and extreme heat alerts*. <https://open.toronto.ca/dataset/>
- TRCA. (2018). STEP Low Impact Development Life Cycle Costing Tool. *Sustainable Technologies Evaluation Program (STEP)*. <https://sustainabletechnologies.ca/lid-lcct/>
- TRCA. (2025). *Low Impact Development*. Toronto and Region Conservation Authority (TRCA).
<https://trca.ca/conservation/creating-green-infrastructure/low-impact-development/>
- United Nations. (2018). *World Urbanization Prospects: The 2018 Revision*.
<https://population.un.org/wup/Publications/Files/WUP2018-KeyFacts.pdf>
- United Nations. (2024). *United Nations Secretary-General's Call to Action on Extreme Heat*.

- U.S. Environmental Protection Agency. (2001). *Economic Valuation of Mortality Risk Reduction: Assessing the State of the Art for Policy Applications*.
<https://archive.epa.gov/ncer/publications/web/pdf/ee-0464-02.pdf>
- U.S. Environmental Protection Agency. (2008a). *Trees and Vegetation* (Reducing Urban Heat Islands: Compendium of Strategies). <https://www.epa.gov/heat-islands/heat-island-compendium>
- U.S. Environmental Protection Agency. (2008b). *Urban Heat Island Basics* (Reducing Urban Heat Islands: Compendium of Strategies). <https://www.epa.gov/heat-islands/heat-island-compendium>
- U.S. Supreme Court. (1941). *Oklahoma ex rel. Phillips v. Guy F. Atkinson Co.*, 313 U.S. 508 (1941). Justia Law. <https://supreme.justia.com/cases/federal/us/313/508/>
- Van Zoest, J., & Hopman, M. (2014). Taking the economic benefits of green space into account: The story of the Dutch TEEB for Cities project. *Urban Climate*, 7, 107–114.
- Vanos, J., Vecellio, D. J., & Kjellstrom, T. (2019). Workplace heat exposure, health protection, and economic impacts: A case study in Canada. *American Journal of Industrial Medicine*, 62(12), 1024–1037. <https://doi.org/10.1002/ajim.22966>
- Venugopal, V., Cai, W., Shanmugam, R., Zhao, M., & PK, L. (2022). Study to Assess the Impacts of Heat Stress on Productivity Losses in India. *Abstracts of the 33rd International Congress on Occupational Health 2022 (ICOH 2022) 6–10 February 2022*, 13, S121.
<https://doi.org/10.1016/j.shaw.2021.12.1132>
- Verlicchi, P., Al Aukidy, M., Galletti, A., Zambello, E., Zanni, G., & Masotti, L. (2012). A project of reuse of reclaimed wastewater in the Po Valley, Italy: Polishing sequence and cost benefit analysis. *Journal of Hydrology*, 432–433, 127–136. Scopus.
<https://doi.org/10.1016/j.jhydrol.2012.02.024>

- Wang, J., Meng, Q., Zou, Y., Qi, Q., Tan, K., Santamouris, M., & He, B.-J. (2022). Performance synergism of pervious pavement on stormwater management and urban heat island mitigation: A review of its benefits, key parameters, and co-benefits approach. *Water Research*, 221, 118755. <https://doi.org/10.1016/j.watres.2022.118755>
- Wang, Y., Berardi, U., & Akbari, H. (2016). Comparing the effects of urban heat island mitigation strategies for Toronto, Canada. *Energy and Buildings*, 114, 2–19. <https://doi.org/10.1016/j.enbuild.2015.06.046>
- White, M. P., Elliott, L. R., Grellier, J., Economou, T., Bell, S., Bratman, G. N., Cirach, M., Gascon, M., Lima, M. L., Löhmus, M., Nieuwenhuijsen, M., Ojala, A., Roiko, A., Schultz, P. W., van den Bosch, M., & Fleming, L. E. (2021). Associations between green/blue spaces and mental health across 18 countries. *Scientific Reports*, 11(1), Article 1. <https://doi.org/10.1038/s41598-021-87675-0>
- Willcott, N., & Cleary. (2022). *The Physical Costs of Climate Change: A Canadian Perspective*. Institute for Sustainable Finance. <https://smith.queensu.ca/centres/isf/pdfs/projects/ISF-Report-PhysicalCostsOfClimateChange.pdf>
- Wilson, J., & Xiao, X. (2023). The Economic Value of Health Benefits Associated with Urban Park Investment. *International Journal of Environmental Research and Public Health*, 20(6), 4815. <https://doi.org/10.3390/ijerph20064815>
- Wilson, S. (2008). *Ontario's wealth, Canada's future: Appreciating the value of the greenbelt's eco-services*. David Suzuki Foundation. <https://davidsuzuki.org/wp-content/uploads/2018/02/ontario-wealth-canada-future-value-greenbelt-eco-services.pdf>
- Wilson, S. (2012). *Canada's Wealth of Natural Capital: Rouge National Park*. David Suzuki Foundation. <https://davidsuzuki.org/wp-content/uploads/2012/09/rouge-national-park-canada-wealth-natural-capital.pdf>

- Wong, N. H., Tan, C. L., Kolokotsa, D. D., & Takebayashi, H. (2021). Greenery as a mitigation and adaptation strategy to urban heat. *Nature Reviews Earth & Environment*, 2(3), 166–181.
<https://doi.org/10.1038/s43017-020-00129-5>
- Wood, L., Hooper, P., Foster, S., & Bull, F. (2017). Public green spaces and positive mental health—Investigating the relationship between access, quantity and types of parks and mental wellbeing. *Health & Place*, 48, 63–71. <https://doi.org/10.1016/j.healthplace.2017.09.002>
- World Bank. (2023). *Assessing the Benefits and Costs of Nature-Based Solutions for Climate Resilience: A Guideline for Project Developers*. World Bank.
<https://www.worldbank.org/en/news/feature/2023/05/22/assessing-the-benefits-and-costs-of-nature-based-solutions-for-climate-resilience-a-guideline-for-project-developers>
- Xia, Y., Li, Y., Guan, D., Tinoco, D. M., Xia, J., Yan, Z., Yang, J., Liu, Q., & Huo, H. (2018). Assessment of the economic impacts of heat waves: A case study of Nanjing, China. *Journal of Cleaner Production*, 171, 811–819. <https://doi.org/10.1016/j.jclepro.2017.10.069>
- Xie, L., Wei, C., Zheng, X., Liu, Y., Wu, W., & Feng, Z. (2023). Who benefits from household energy transition? A cost-benefit analysis based on household survey data in China. *China Economic Review*, 77, 101878. <https://doi.org/10.1016/j.chieco.2022.101878>
- Yang, L., Qian, F., Song, D.-X., & Zheng, K.-J. (2016). Research on Urban Heat-Island Effect. *Procedia Engineering*, 169, 11–18. <https://doi.org/10.1016/j.proeng.2016.10.002>
- Yang, S., Ding, L., & Prasad, D. (2022). A multi-sector causal network of urban heat vulnerability coupling with mitigation. *Building and Environment*, 226, 109746.
<https://doi.org/10.1016/j.buildenv.2022.109746>
- Yin, R. K. (2007). *Case study research: Design and methods* (3. ed.,). Sage.

- Yin, Y., Li, S., Xing, X., Zhou, X., Kang, Y., Hu, Q., & Li, Y. (2024). Cooling Benefits of Urban Tree Canopy: A Systematic Review. *Sustainability*, 16(12), Article 12.
<https://doi.org/10.3390/su16124955>
- York Region. (2021). *State of the Forest*. <https://trcaca.s3.ca-central-1.amazonaws.com/app/uploads/2023/07/07183847/2021-State-Of-The-Forest-Report.pdf>
- York Region. (2022, February 11). *Understanding York Region's Population*.
<https://www.york.ca/newsroom/campaigns-projects/understanding-york-regions-population>
- York Region. (2024a). *Approved 2025 Budget*. <https://www.york.ca/york-region/finances/budgets>
- York Region. (2024b). *York Region Agriculture and Agri-Food Sector Strategy 2024-2027*.
<https://www.yorklink.ca/wp-content/uploads/2024/11/2024-2027-yr-agriculture-agrifood-sector-strategy.pdf>
- Young, R. A. (2005). Economic criteria for water allocation and valuation. In *Cost-Benefit Analysis and Water Resources Management* (pp. 13–45). Edward Elgar Publishing.
- Zander, K. K., Botzen, W. J. W., Oppermann, E., Kjellstrom, T., & Garnett, S. T. (2015). Heat stress causes substantial labour productivity loss in Australia. *Nature Climate Change*, 5(7), 647–651. <https://doi.org/10.1038/nclimate2623>
- Zander, K. K., & Mathew, S. (2019). Estimating economic losses from perceived heat stress in urban Malaysia. *Ecological Economics*, 159, 84–90. <https://doi.org/10.1016/j.ecolecon.2019.01.023>
- Zhou, R. (2017). *Assessing the Changes in Urban Tree Canopy Cover, Ecosystem Services, Streamflow and Pollutants in Corpus Christi, Texas Using I-tree Applications* [Master's Thesis, Texas A&M University-Kingsville].
<https://search.proquest.com/openview/08f7390939a9ba526836d6a34c239dbd/1?pq-origsite=gscholar&cbl=18750>

Zupancic, T., Westmacott, C., & Bulthuis, M. (2015). *THE IMPACT OF GREEN SPACE ON HEAT AND AIR POLLUTION IN URBAN COMMUNITIES: A META-NARRATIVE SYSTEMATIC REVIEW*. <https://davidsuzuki.org/wp-content/uploads/2017/09/impact-green-space-heat-air-pollution-urban-communities.pdf>

Appendix A

Table 8: Annual Benefits Adjusted for Canopy Growth Over Time (without discounting)

Year	Moderate Scenario Benefits		Intense Scenario Benefits	
1	\$	5,521,091.96	\$	5,521,091.96
2	\$	5,778,627.51	\$	5,914,421.51
3	\$	6,379,543.79	\$	6,832,190.46
4	\$	7,323,840.80	\$	8,274,398.81
5	\$	8,611,518.55	\$	10,241,046.55
6	\$	10,242,577.02	\$	12,732,133.70
7	\$	12,217,016.23	\$	15,747,660.25
8	\$	14,534,836.17	\$	19,287,626.20
9	\$	17,196,036.85	\$	23,352,031.54
10	\$	20,200,618.25	\$	27,940,876.29
11	\$	23,548,580.39	\$	33,054,160.43
12	\$	27,239,923.26	\$	38,691,883.98
13	\$	31,274,646.86	\$	44,854,046.92
14	\$	35,652,751.19	\$	51,540,649.26
15	\$	40,374,236.25	\$	58,751,691.01
16	\$	45,439,102.05	\$	66,487,172.15
17	\$	50,847,348.58	\$	74,747,092.69
18	\$	56,598,975.84	\$	83,531,452.63
19	\$	62,693,983.83	\$	92,840,251.97
20	\$	69,132,372.56	\$	102,673,490.71
21	\$	75,914,142.01	\$	113,031,168.85
22	\$	83,039,292.20	\$	123,913,286.39
23	\$	90,507,823.12	\$	135,319,843.33
24	\$	98,319,734.77	\$	147,250,839.67
25	\$	106,475,027.16	\$	159,706,275.41
26	\$	114,973,700.27	\$	172,686,150.54
27	\$	123,815,754.12	\$	186,190,465.08
28	\$	133,001,188.70	\$	200,219,219.02
29	\$	142,530,004.01	\$	214,772,412.35
30	\$	152,402,200.06	\$	229,850,045.09
31	\$	162,617,776.83	\$	245,452,117.22
32	\$	173,176,734.34	\$	261,578,628.75
33	\$	184,079,072.58	\$	278,229,579.69
34	\$	195,324,791.55	\$	295,404,970.02
35	\$	206,913,891.26	\$	313,104,799.75
36	\$	218,846,371.69	\$	331,329,068.89

Year	Moderate Scenario Benefits		Intense Scenario Benefits	
37	\$	231,122,232.86	\$	350,077,777.42
38	\$	243,741,474.76	\$	369,350,925.35
39	\$	256,704,097.39	\$	389,148,512.68
40	\$	270,010,100.76	\$	409,470,539.41
Total	\$	3,814,323,038.42	\$	5,709,101,993.92

Table 9: Annual Present Value (PV) of Costs and Benefits for the Moderate Coverage Scenario

Year	PV of Benefits		PV of Costs	Cash Flow
1	\$	5,360,283.46	-\$130,316,145,815.80	-\$130,310,785,532.34
2	\$	5,446,910.65	-\$25,605,127.72	-\$20,158,217.07
3	\$	5,838,186.29	-\$24,859,347.30	-\$19,021,161.01
4	\$	6,507,137.69	-\$24,135,288.64	-\$17,628,150.95
5	\$	7,428,371.55	-\$23,432,319.07	-\$16,003,947.53
6	\$	8,577,997.01	-\$22,749,824.34	-\$14,171,827.34
7	\$	9,933,552.19	-\$22,087,208.10	-\$12,153,655.91
8	\$	11,473,933.89	-\$21,443,891.36	-\$9,969,957.46
9	\$	13,179,330.37	-\$20,819,312.00	-\$7,639,981.63
10	\$	15,031,157.12	-\$20,212,924.27	-\$5,181,767.15
11	\$	17,011,995.51	-\$19,624,198.32	-\$2,612,202.81
12	\$	19,105,534.11	-\$19,052,619.73	\$52,914.38
13	\$	21,296,512.68	-\$18,497,689.06	\$2,798,823.63
14	\$	23,570,668.64	-\$17,958,921.41	\$5,611,747.22
15	\$	25,914,685.91	-\$17,435,846.03	\$8,478,839.87
16	\$	28,316,146.15	-\$16,928,005.86	\$11,388,140.29

Year	PV of Benefits	PV of Costs	Cash Flow
17	\$ 30,763,482.12	-\$16,434,957.14	\$14,328,524.98
18	\$ 33,245,933.20	-\$15,956,269.07	\$17,289,664.13
19	\$ 35,753,502.94	-\$15,491,523.37	\$20,261,979.57
20	\$ 38,276,918.51	-\$15,040,313.95	\$23,236,604.56
21	\$ 40,807,592.07	-\$14,602,246.55	\$26,205,345.52
22	\$ 43,337,583.88	-\$14,176,938.40	\$29,160,645.48
23	\$ 45,859,567.14	-\$13,764,017.87	\$32,095,549.28
24	\$ 48,366,794.48	-\$13,363,124.14	\$35,003,670.34
25	\$ 50,853,065.96	-\$12,973,906.93	\$37,879,159.02
26	\$ 53,312,698.61	-\$12,596,026.15	\$40,716,672.46
27	\$ 55,740,497.44	-\$12,229,151.60	\$43,511,345.84
28	\$ 58,131,727.73	-\$11,872,962.72	\$46,258,765.01
29	\$ 60,482,088.72	-\$11,527,148.27	\$48,954,940.45
30	\$ 62,787,688.55	-\$11,191,406.09	\$51,596,282.46
31	\$ 65,045,020.31	-\$10,865,442.80	\$54,179,577.50
32	\$ 67,250,939.40	-\$10,548,973.60	\$56,701,965.80
33	\$ 69,402,641.84	-\$10,241,721.94	\$59,160,919.90
34	\$ 71,497,643.74	-\$9,943,419.36	\$61,554,224.38
35	\$ 73,533,761.73	-\$9,653,805.20	\$63,879,956.53
36	\$ 75,509,094.34	-\$9,372,626.41	\$66,136,467.93
37	\$ 77,422,004.36	-\$9,099,637.29	\$68,322,367.07

Year	PV of Benefits	PV of Costs	Cash Flow
38	\$ 79,271,102.01	-\$8,834,599.31	\$70,436,502.70
39	\$ 81,055,229.02	-\$8,577,280.89	\$72,477,948.14
40	\$ 82,773,443.47	-\$8,327,457.17	\$74,445,986.30
TOTAL	\$ 1,624,964,950.14	-\$130,917,673,295.24	
NPV			-\$129,293,200,870.47
BCR			0.01

Table 10: Annual Present Value (PV) of Costs and Benefits for the Intense Coverage Scenario

Year	PV of Benefits	PV of Costs	Cash Flow
1	\$ 5,360,283.46	-\$260,594,317,044.53	-\$260,588,956,761.08
2	\$ 5,574,909.52	-\$51,202,983.90	-\$45,628,074.38
3	\$ 6,252,422.11	-\$49,711,634.85	-\$43,459,212.74
4	\$ 7,351,696.17	-\$48,263,723.16	-\$40,912,026.99
5	\$ 8,834,016.72	-\$46,857,983.65	-\$38,023,966.93
6	\$ 10,662,961.53	-\$45,493,188.01	-\$34,830,226.48
7	\$ 12,804,288.87	-\$44,168,143.70	-\$31,363,854.83
8	\$ 15,225,830.23	-\$42,881,692.91	-\$27,655,862.69
9	\$ 17,897,387.71	-\$41,632,711.56	-\$23,735,323.86
10	\$ 20,790,636.02	-\$40,420,108.32	-\$19,629,472.29
11	\$ 23,879,028.78	-\$39,242,823.61	-\$15,363,794.83
12	\$ 27,137,708.95	-\$38,099,828.74	-\$10,962,119.80

Year		PV of Benefits	PV of Costs	Cash Flow
13	\$	30,543,423.35	-\$36,990,125.00	-\$6,446,701.64
14	\$	34,074,440.95	-\$35,912,742.71	-\$1,838,301.76
15	\$	37,710,474.80	-\$34,866,740.50	\$2,843,734.30
16	\$	41,432,607.57	-\$33,851,204.37	\$7,581,403.20
17	\$	45,223,220.36	-\$32,865,246.96	\$12,357,973.40
18	\$	49,065,924.84	-\$31,908,006.76	\$17,157,918.09
19	\$	52,945,498.43	-\$30,978,647.34	\$21,966,851.09
20	\$	56,847,822.41	-\$30,076,356.64	\$26,771,465.77
21	\$	60,759,822.97	-\$29,200,346.25	\$31,559,476.72
22	\$	64,669,414.93	-\$28,349,850.73	\$36,319,564.20
23	\$	68,565,448.01	-\$27,524,126.92	\$41,041,321.09
24	\$	72,437,655.74	-\$26,722,453.32	\$45,715,202.42
25	\$	76,276,606.58	-\$25,944,129.44	\$50,332,477.14
26	\$	80,073,657.51	-\$25,188,475.18	\$54,885,182.33
27	\$	83,820,909.67	-\$24,454,830.27	\$59,366,079.39
28	\$	87,511,166.17	-\$23,742,553.66	\$63,768,612.51
29	\$	91,137,891.90	-\$23,051,022.97	\$68,086,868.93
30	\$	94,695,175.25	-\$22,379,633.96	\$72,315,541.29
31	\$	98,177,691.64	-\$21,727,799.96	\$76,449,891.68
32	\$	101,580,668.88	-\$21,094,951.41	\$80,485,717.47
33	\$	104,899,854.16	-\$20,480,535.35	\$84,419,318.81

Year		PV of Benefits	PV of Costs	Cash Flow
34	\$	108,131,482.63	-\$19,884,014.91	\$88,247,467.73
35	\$	111,272,247.61	-\$19,304,868.84	\$91,967,378.76
36	\$	114,319,272.13	-\$18,742,591.11	\$95,576,681.02
37	\$	117,270,082.04	-\$18,196,690.40	\$99,073,391.64
38	\$	120,122,580.33	-\$17,666,689.71	\$102,455,890.62
39	\$	122,875,022.80	-\$17,152,125.93	\$105,722,896.87
40	\$	125,525,994.95	-\$16,652,549.44	\$108,873,445.51
TOTAL	\$	2,413,737,228.66	-\$261,797,201,176.98	
NPV				-\$259,383,463,948.32
BCR				0.01