The GHG Emission Reduction Toolkit

A Case Study of Blacktown City, Australia

Thesis submitted for the Degree of

Doctor of Philosophy

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In loving memory of

Associate Professor Sergiy Kharkivskiy

STATEMENT OF AUTHENTICATION

The work presented in this thesis is, to the best of my knowledge and belief, original except as acknowledged in the text. I hereby declare that I have not submitted this material, either in full or in part, for a degree at this or any other institution.

Hoda Karimipour
June 2020
[redacted]

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Acknowledgement

A PhD was never part of my plan (they were for the "smart" people); thus, it has been an interesting and often overwhelming experience. It is hard to identify the biggest learning curve, whether it has been the topic itself, or writing publications, giving presentations, or staying focused. Nonetheless, it would not have been possible without the support of those around me. While it is only possible to give particular mention to some here, I am grateful to everyone who has supported me in writing this thesis.

First, I extend my sincere appreciation to my principal supervisor, Professor Vivian WY Tam, whose belief in my abilities ultimately convinced me to pursue my doctoral research. She has supported me through the years and enabled me to meet many industry professionals and publish my papers. She has been available round the clock, answered all of my enquiries and questions, and guided me. Second, I want to express my gratitude to Associate Professor Khoa Lee and Professor Liyin Shen for finding the time to help me, for showing interest in my research, and reviewing my papers.

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Finally, I thank my parents and my sisters, who cared for my son when I was abroad for my PhD; they have made me who I am today.

Hoda Karimipour

Abstract

This PhD thesis is in line with Australia's national policy of a 26-28% reduction in its greenhouse gas emissions to 2005 levels. According to a review of its climate change policy in 2017, the Australian Government is committed to tackling climate change, while maintaining a strong economy, providing affordable energy and security for industries. This requires new initiatives in existing technologies to reduce greenhouse gas emissions or the emergence of new technologies altogether. Whatever the strategy, the final goal is to mitigate greenhouse gas emissions. This national target is now disseminated among different sectors and governmental bodies in Australia, requesting them to submit their action plans against climate change. This includes all Australian City Councils and incorporates Blacktown City Council as the Case Study for this study.

As part of the Blacktown City Council's commitment to reduce greenhouse gas emissions, this research study is the result of collaboration between the Council and Western Sydney University. The authorities of both sides have signed a research collaboration agreement, ample evidence of a local university tackling local problems. This research agreement is unique as it opens a door for other local Councils to collaborate with universities. Blacktown City Council, on the other side of this agreement, can improve its body of knowledge through a comprehensive investigation of greenhouse gas mitigation using its available tools. Therefore, this research study developed a toolkit to help reduce the Council's GHG Emission. The research areas of this study are as follows:

1. Investigating possible solutions for reducing GHG emissions of the Council's fleet.
2. Investigating scenarios for reducing GHG emissions from the Council's waste.
3. Investigating the effects of urban land useon reducing heat islands.
4. Investigating solutions to reduce energy consumption in the Council's buildings.

To cover area 1, this study investigates the impact of route optimization of heavy vehicles on greenhouse gas mitigation. The distance driven by different types of heavy vehicles has been quantified in their optimized route and compared to regular routes. The results in this section show that using the optimized route rather than the regular route can reduce the distance driven by tree maintenance trucks by 60%, fuel consumption by 62%, and GHG

emissions by 62%, per month. In addition, considering the optimized route for garbage trucks, it is possible to reduce 10% of km travelled, 11% fuel consumed, and 10% GHG emitted, per month.

To cover area 2, this study proposed strategies for general waste mitigation at their origin points. The main purpose of this part of the study was to measure proportions of waste categories in public facilities, identify potential opportunities for general waste reduction, and quantify the GHG emissions reduction that each opportunity might achieve. For this purpose, two public facilities of different types were selected, a library and an aquatic center and a waste audit was undertaken in each. The results in this section show that removing organic food from the waste stream at 10 public facilities of the Council could reduce GHG emissions by about 0.805 tCO2-e/year. However, separately transporting that waste would emit 7.13 tCO2-e/year. Therefore, the separated food waste would need to be processed on-site, for example, using worm farms. Removing coffee cups from the landfill waste stream could reduce the associated landfill GHG emissions by around 0.275 tCO2-e/year for the 10 public facilities. The study also recommended separating plastic bags from the landfill waste stream of these facilities to reduce 1.10 tonnes of plastic bags from landfills each year.

To cover area 3, this study proposed and investigated different cooling street strategies to reduce the Heat Islands Effects. In particular, it investigated two different cooling street strategies, including green canopy cover and high reflective pavement. These scenarios have been simulated and compared to the baseline scenario at the Case study of the project-Blacktown City. ENVI-Met software has been used to simulate and quantify the microclimate processes before and after introducing the street cooling strategies. The results in this section show that replacing the asphalt pavement parking with light concrete pavement parking will reduce surface temperature by up to 20°C. Planting short to medium height trees alongside the street will reduce the air temperature by up to 3°C and surface temperature by up to 11°C. In addition, by implementing these two street cooling scenarios simultaneously, the sensible heat flux will decrease 380 W/m2.

To cover area 4, this study analyzed the green initiatives undertaken by Blacktown City Council to reduce its energy consumption. For this purpose, it compares different types of measures in their level of emission reduction, cost, and payback period. The results in this section show that installing energy saving units has been the most cost-efficient measure. Its cost per tonne of GHG reduction ranges from $132 for 350 KvA energy saving unit in Blacktown stadium to $160 for 450 KvA unit in the aquatic center. The next cost-effective action is retrofitting dog kennel heaters to higher efficiency units, replacing electric hot water systems with solar hot water systems and affixing variable speed drives to pool motors with 217, 262, and 354 dollars per tonne of GHG reduction. Considering the payback times of the measures, the shortest payback time of all measures was one year, which was allocated to the installation of 350 KvA energy saving unit.

Finally, the GHG emission reduction toolkit was presented at the end of this thesis. Considering the four different areas examined in this research, this study presents a carbon footprint reduction toolkit in four sectors. This toolkit is a general guideline to mitigate GHG emission and can be used anywhere else in the world. However, some further studies are necessary for putting this toolkit into action. Further studies in this field can focus on developing a quantified toolkit to enable city planners to estimate GHG reduction after implementing each action.

Preface

This dissertation is submitted for the degree of Doctor of Philosophy and is the result of research undertaken at Western Sydney University. The research described herein was conducted under the supervision of Prof. Vivian WY Tam and Dr. Khoa Lee from the School of Computing, Engineering & Mathematics, and Prof. Liyin Shen from Chongqing University. This dissertation represents a culmination of work and learning by the candidate from June 2016 to June 2019.

To date, this work has led to three journal papers, along with five conference papers and a book chapter, and additional work resulting from the doctoral research (listed below).

Journal

- Tam, V. **Karimipour, H.** N. Le, K. Wang, J. (2018). "Green Neighborhood: Review on the International Assessment Systems". *Renewable and Sustainable Energy Reviews*. Vol 82, pp 689-699.

- **Karimipour, H.** Tam, V. Burnie, H, Le, K. (2018). "Quantifying the Effects of General Waste Reduction on Greenhouse-Gas Emissions at Public Facilities". *Journal of the Air and Waste Management Association*. Volume 69, Issue 10, pp 1247-1257. Doi: 10.1080/10962247.2019.1642967

- **Karimipour, H.** Tam, V. Burnie, H, Le, K. (2017). "Vehicle Routing Optimization for Improving Fleet Fuel Efficiency: A Case Study in Sydney, Australia". *International Journal of Environmental Science and Development*. Vol 8, no. 11. pp 776-780.

- **Karimipour, H.** Tam, V. Burnie, H, Le, K. (2020). "Simulating Cooling Street Strategies on Urban Heat Islands Effects: An Empirical Study for Blacktown City, Australia". *Journal of Cleaner Production*. Submitted, Under revision.

Conference

- **Hoda Karimipour,** Vivian W. Y. Tam, Helen Burnie, Khoa N Le, "Towards Low Carbon Footprint: A Case Study of Sydney, Australia", 1st International Conference on Construction Project Management and Construction Engineering (iCCPMCE-2018), **Sydney, Australia, 3-5 December 2018.**

- **Hoda Karimipour,** Vivian W. Y. Tam, Khoa N. Le, "Quantifying Potential General Waste Reduction at Public Facilities", 23rd International Conference on Advancement of Construction Management and Real Estate (CRIOCM 2018), **Guiyang, China, 24-29 August 2018.**

- **Karimipour, H,** Tam, V. W. Y, Le, K. "Feature Based Comparison of International Green Neighbourhood Assessment Systems", International Conference on Innovative Production and Construction (IPC 2016), **Perth, Australia, 30 Nov 2017- 1 Dec 2017.**

- **Hoda Karimipour,** Vivian W. Y. Tam, Helen Burnie, Khoa N Le, "Vehicle Routing Optimization for Improving Fleet Fuel Efficiency: A Case Study in Sydney, Australia", 2nd Asia Conference on Environment and Sustainable Development (ACESD 2017), **Tokyo, Japan, 2-4 Nov 2017.**

- **Hoda Karimipour,** Vivian W. Y. Tam, Khoa N. Le, "Theme Based Comparison of International Green Neighbourhood Assessment Systems", 22nd International Conference on Advancement of Construction Management and Real Estate (CRIOCM 2017), **Melbourne, Australia, 20-23 November 2017.**

Book Chapter

- I.M. Chethana S. Illankoon, Vivian W.Y. Tam, **Hoda Karimipour** and Khoa N. Le. (2019). 'Introduction' in Vivian WY Tam and Khoa Lee, *Sustainable Construction Technologies, Life Cycle Assessment.* United Kingdom: Butterworth-Heinemann, pp.1-23.

In addition to contributions by the supervisory panel (Tam, WY. V, Le, K, Shen, L), additional contributions were by two engineering professionals. Dr. Helen Burnie from Blacktown City Council was the project supervisor in the Council, leading the meetings, acquisition of data, coordination with authorities in the Council, reviewing the reports and journal articles and providing direction in the scope of analysis.

In addition, Mr. Jon Bannister, Plant & Energy Manager of Blacktown City Council, supported the project for the route optimization of the Council's truck. Mr. Richard Wiezel, Senior Coordinator City Image of Blacktown City Council, provided valuable information, data, and supportive ideas for optimizing the truck's routs. Mr. Leslie Leedham and Mr. Noel Weir contributed to the brain storming meetings and provided us with input data and their noteworthy feedback on the first model.

The candidate undertook several months of professional consultancy in the Blue Mountain's Energy Efficiency Project. In this project, a professional team headed by Prof. Vivian Tam and Dr. Khoa Lee, led a team of energy experts to prepare the energy consumption report for the Council's asset and propose the energy efficiency scenarios for each. This report was prepared and drafted by the candidate and was approved by Prof. Tam. The project was "*The Carbon Reduction Toolkit for Blue Mountain City Council- Phase I: Energy Efficiency*", (2017), Blue Mountains City Council.

CHAPTER 1

Introduction

SUMMARY

This chapter presents the climate change global problem in general and its specific impact on Australia's sensitive climate, which is the pilot country for this study. The global action against climate change and Australia's National and State Policies to Mitigate Greenhouse Gas Emission is introduced in this chapter.

1. Background and Problem Statement

Climate change has become a global issue influencing human survival and development (Ganaut, 2011). According to a new report by the United Nations, 2016 was recorded as the earth's warmest year in recorded history. In addition, 2015 was warmer than 2014, which was warmer than 2013; this is not mere coincidence (NASA, 2017) but a gradual trend in the earth's temperature, which is permanent. Worryingly, the impact of climate change in the long-term is still unknown. Having warmer weather may seem pleasant, especially for very cold regions such as Scandinavia, Iceland, or Canada. Walking around in the late winter in spring-like-weather is not a bad experience at all in the freezing regions of the world. However, there are downsides to warmer weather, which are concerning. For example, considerable changes in precipitation will reduce the agricultural crop yield. The rising sea level threatens some shorelines or small islands, which may go underwater forever. New diseases emerge as the result of changing seasons and precipitation patterns. Long-term drought leads to famine, such as in Somalia and Ethiopia, and natural disaster makes poor countries even poorer. Regardless of where we live, climate change will surely affect many aspects of our lives.

Figure 1 represents the entire temperature dataset of the NASA GISS, including monthly average values since 1880, projected against the climate average baseline for 1951-1980. This implies a deviation of +1.35 degrees Celsius for February 2016, compared to "the average climate of around 1965." Many scientists believe that CO_2 climate sensitivity is in fact higher than most think; therefore, the temperature graph will at some point grow to a higher trend not yet visible (Schuttenhelm, 2016). This is a serious warning for the globe; we do not have much time. The disaster has already begun and we will face the consequences very soon.

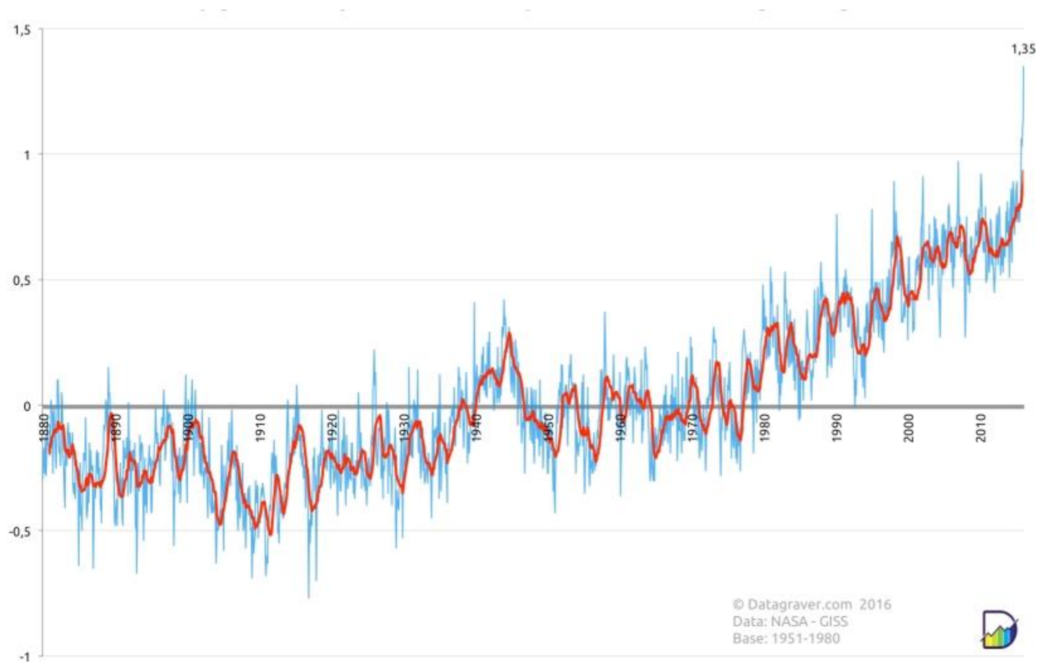


Figure 1: Monthly global temperature anomaly+12-month moving average in °C (GISTEMP Team, 2020)

1.1. Global Action against Climate Change

Considering this concerning trend, governments need to take action. Climate change mitigation plans need to be active in policies and legislations. Governments must make massive investments to expand the body of knowledge on climate change, develop resilient cities, and improve crisis management. They must prepare and implement short and long-term plans. Governmental subsidies need to be allocated to green infrastructure and renewable energies. Furthermore, governments must introduce and advertise promotion plans to raise awareness of the causes and effects of climate change. We need to build resilient cities and communities to minimize the impacts of hot waves and low precipitation. It is necessary to introduce and distribute new technologies for energy efficient equipment and appliances into marketplaces at reasonable prices. At the social level, we need to raise awareness to mitigate energy consumption, household waste, and the water use per capita. Our communities must take responsible action against climate change. People must understand their roles in rising temperatures and learn to mitigate it at the personal level.

To address these concerns, 174 countries and the European Union came together on April 17, 2016, to sign the Paris Agreement on Climate Change. This is a 29-article Agreement of the United Nations, which highlights the following consent to climate change and implies the associated actions against each aspect (United Nations, 2015a):

- ***Article 2:*** Aims to strengthen the global response to the threat of climate change, in the context of sustainable development by increasing the ability to adapt to the adverse impacts of climate change and foster climate resilience and low greenhouse gas emissions development, in a manner that does not threaten food production.
- ***Article 4:*** To achieve the long-term temperature goal set in Article 2, Parties aim to reach global peaking of greenhouse gas emissions as soon as possible. All Parties should strive to formulate and communicate long-term low GHG emission development strategies.
- ***Article 5:*** Parties should take action to conserve and enhance, as appropriate, sinks and reservoirs of greenhouse gases.
- ***Article 6:*** Parties should promote the mitigation of greenhouse gas emissions while fostering sustainable development. In addition, they must incentivize and facilitate participation in the mitigation of greenhouse gas emissions by authorized public and private entities.
- ***Article 10:*** Parties share a long-term vision on the importance of fully realizing technology development and transfer, to improve resilience to climate change and reduce greenhouse gas emissions.
- ***Article 13:*** A national inventory report of anthropogenic emissions by sources and removals by sinks of greenhouse gases, prepared using good practice methodologies accepted by the Intergovernmental Panel on Climate Change and agreed upon by the Conference of the Parties serving as the meeting of the Parties to this Agreement.
- ***Article 21:*** This Agreement shall enter into force on the thirtieth day after the date on which at least 55 Parties to the Convention accounting in total for at least an estimated 55% of the total global greenhouse gas emissions have deposited their instruments of ratification, acceptance, approval, or accession.

As is clear from this agreement, all parties need to act in areas of

- Adapt to the adverse impacts of climate change
- Reach global peaking of greenhouse gas emissions
- Conserve and enhance sinks and reservoirs of greenhouse gases
- Promote the mitigation of greenhouse gas emissions by public and private entities

- Develop technologies to improve resilience to climate change
- Reduce a national inventory by enhancing the sinks and removal of the sources of greenhouse gases.

In particular, the Paris Agreement aims to limit a global temperature rise in this century to "well below" 2 degrees Celsius over pre-industrial levels, and to try to hold the increase to 1.5 degrees. The Agreement entered into force on November 4, 2016, and most of its provisions take practical effect from 2020.

The United Nations Sustainable Development Goals is another agreement that addresses climate change at the global level. In this 8-goal document signed in 2015, the members agreed to (United Nations, 2015b):

- ***Target 1-5:*** By 2030, build resilience of the poor and vulnerable, and reduce their exposure and vulnerability to climate-related extreme events and other economic, social, and environmental shocks and disasters.
- ***Target 7.1:*** By 2030, ensure universal access to affordable, reliable, and modern energy services.
- ***Target 7.2:*** By 2030, increase substantially the share of renewable energy in the global energy mix.
- ***Target 7.3:*** By 2030, double the global rate of improvement in energy efficiency.
- ***Target 13.1:*** Strengthen resilience and adaptive capacity to climate-related hazards and natural disasters in all countries.
- ***Target 13.3:*** Improve education, awareness-raising, and human and institutional capacity on climate change.

1.2. Cities at the Heart of the Green Revolution

These two global agreements on climate change mitigation, entail all parties to take appropriate action at their national, provincial, and local level. All these international commitments need to be adapted to the specific conditions of each country for implementation. Every country must present its specific contribution to greenhouse gas mitigation to the United Nations and report its progress every five years. Countries then need to disseminate their national commitment to provincial and local governments to take suitable actions.

However, cities are at the very center of the "Green revolution" to reduce greenhouse gas emissions (Jammazi & Aloui, 2015; Vijayaraghavan, 2016). All the related legislations at the higher scale can be put into action at the city level. Most policies at the national and state level are long-term plans that must be translated into associated action plans at the executive level. This is where actual implementation plans will be identified and produced in response to the overhead policies. Consequently, several urban initiatives at the city level can develop greener, healthier, and lower emission communities. One of these initiatives is the carbon reduction toolkit at the neighborhood level, which is probably the very first attempt to connect sustainable city principles with micro-level community planning (Denis-Jacob, 2011; Wang, Zhao, He, Wang, & Peng, 2016). The carbon reduction toolkit will help local authorities at the city level to define and formulate actions against climate change in each sector. This toolkit can be a quantified spreadsheet that determines the required actions in each sector with their temporal attributes and range of effects. This chapter explains the attributes of the toolkits introduced in this study.

1.3. Australia's National and State Policies to Mitigate Greenhouse Gas Emission

In line with the Paris Agreement on Climate Change and the United Nations Sustainable Development Goals 2030, the Australian Government has prepared national and state climate change policies. At the national level, the Australian government has developed the "*2017 Review of Climate Change Policies.*" This policy document is the Australian government's commitment to deal with climate change, while maintaining a strong economy, affordable energy, and security for industries. The government recognizes that in reducing emissions and meeting international commitments it is necessary to balance economic impacts. Australia's contribution to climate change is relatively small at around 1.3%; however, its per percent emission is one of the highest in the world with 18.3 tonnes per year per person. Therefore, Australia is a high emission country, and this situation requires intervention. Therefore, Australia committed to reduce its national emission by 26-28% below the 2005 level by 2030. Thus, all policies and plans at the national, state, and local levels must adapt to meet the national commitment for greenhouse gas emission mitigation (Department of the Environment and Energy, 2017).

At the state level, New South Wales (NSW) has developed the Climate Change Policy Framework for NSW in 2016 through the Office of Environment and Heritage. In this policy framework, NSW has committed to reach net-zero emission by 2050 and to be more resilient in response to changing climate. At the state level, NSW developed the "*NSW Climate Change Policy Framework*" highlighting the following directions (Office of Environment and Heritage, 2016):

- Create a certain investment environment by working with the Commonwealth to manage transition.
- Boost energy productivity; put downward pressure on household and business energy bills.
- Take advantage of opportunities to grow new industries in NSW.
- Reduce risks and damage to public and private assets in NSW arising from climate change.
- Reduce climate change impacts on health and wellbeing.
- Manage impacts on natural resources, ecosystems, and communities.

2. Main Objectives of the Thesis

In line with the Australian Climate Change Policy and NSW Climate Change Policy Framework, this research project has emerged as a response to climate change at the local level. The main aim of this research project is to prepare a GHG emission reduction toolkit for Blacktown City Council to mitigate its GHG emissions at the city level. For this purpose, four key areas have been identified and will be examined in this toolkit, including:

1. GHG emission reduction toolkit in transportation
2. GHG emission reduction toolkit in waste management
3. GHG emission reduction toolkit by managing urban Land Use
4. GHG emission reduction toolkit by Increasing Energy Efficiency

It needs to be clarified that the four main mentioned areas are the main episodes of the toolkit. This toolkit would suggest the potential tactics for GHG emission reduction at the city level and would be a beneficial instrument for policymakers and city planners to lead their municipal level program accordingly. The four mentioned areas are the major GHG emitters in a city, as explained in section 5 of chapter 2. Therefore, the objective of this study is to propose the GHG emission reduction potential in each part and to examine a single tool for each episode in Blacktown City. Piloting a tool from a comprehensive toolkit and quantifying its GHG emission abatement potential, would make a way forward for the other tools to be quantified and calibrated for each region. Quantifying the GHG abatement potential of all the tools in this toolkit was beyond the boundary of this research. Figure 2 illustrates the linkage between the main objectives of the study, the episodes of a GHG emission reduction toolkit, and the selected tools to be quantified in this research.

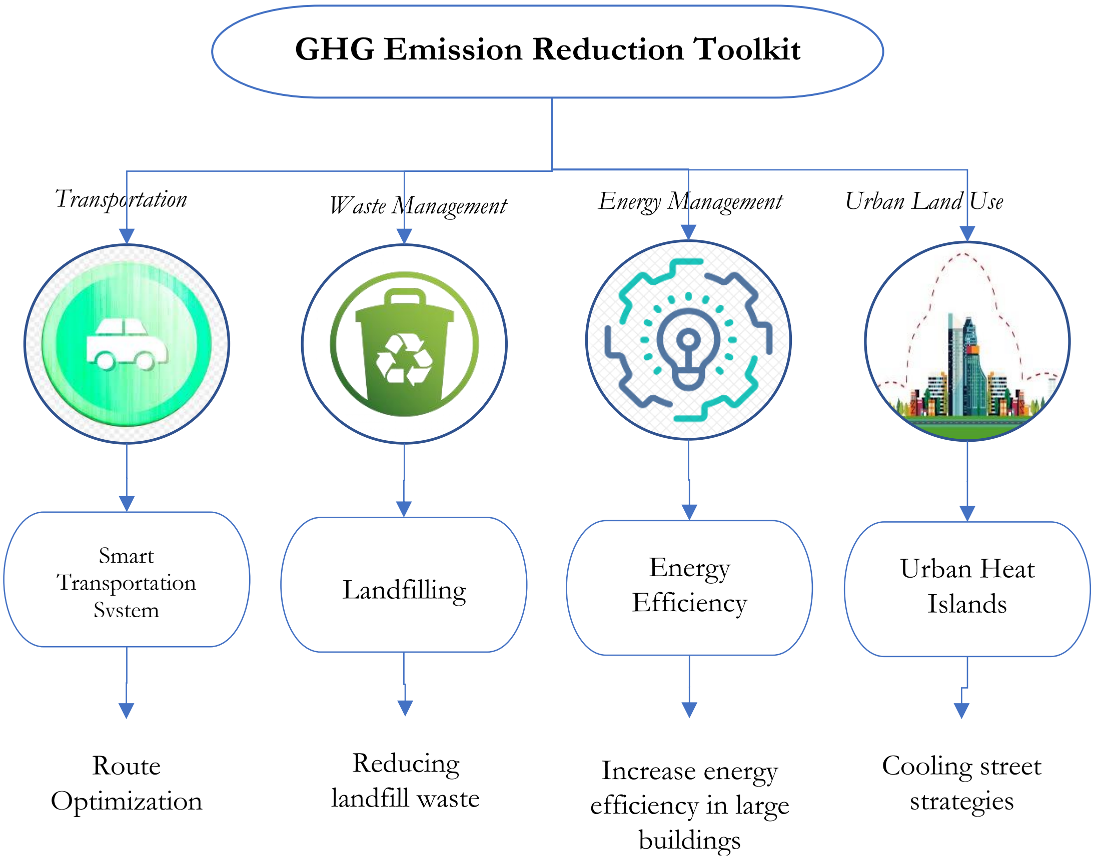


Figure 2: The linkage between the main objectives of the research, the episodes of the GHG emission reduction toolkit and selected tools

Table 1 illustrates the cross relationship between the four key areas of this research with the associated national, state, and local level policies for greenhouse gas mitigation. According to this table, the current research is in line with the Safeguard Mechanism and National Energy Productivity Plan at the national level and Policy Commitment 1, 2, 3 of the Blacktown City Council. In addition, it has several cross references with the New South Wales Policy Direction.

Table 1: Cross-reference matrix for the national, state, and Council's policies with the key research areas of this study (Australian Government, 2016, 2017)

	2017 Review of Climate Change Policies	NSW Climate Change Policy Framework	Blacktown- Responding to Climate Change Policy
GHG emission reduction toolkit in transportation	Safeguard Mechanism (As a part of Emissions Reduction Fund)	Boost energy productivity, put downward pressure on household and business energy bills	Mitigate the impacts of urban heat in our operations, own new assets and buildings, and when undertaking major facility upgrades
GHG emission reduction toolkit in waste management	Safeguard Mechanism (As a part of Emissions Reduction Fund)	Boost energy productivity, put downward pressure on household and business energy bills	Mitigate the impacts of urban heat in our operations, own new assets and buildings, and when undertaking major facility upgrades
GHG emission reduction toolkit by lowering the heat islands effects	–	Reduce climate change impacts on health and wellbeing	Increase tree canopy cover and vegetation in streets and reserves
GHG emission reduction toolkit by lowering the electricity usage	National Energy Productivity Plan (NEPP)	Boost energy productivity, put downward pressure on household and business energy bills	Achieve net-zero emissions from the electricity, fuel and gas used in our operations by 2030.

3. Research Methodologies

The objective of this study is to develop a GHG emission reduction toolkit and examine it in an urban scale. The four main episodes of the thesis are: Transportation, Waste

Management, Urban Land Use, and Energy Management. Because of the multidisciplinary nature of the research, different methodologies have been used for various sectors. Details were provided in associated sections; however, a summary of the methods comes below:

Transportation

To design a GHG emission reduction toolkit for the transportation sector and according to the agreement with Blacktown City Council, this study investigated route optimization for the Council's heavy trucks. In particular, it examined the effects of optimizing the route of heavy vehicles on their fuel consumption and GHG emissions. Therefore, this study selected two types of the Council's heavy trucks, A waste collector and a tree maintenance truck with different missions and operations.

To optimize the route for these two heavy trucks, this study used the Network Analysis module in Geographical Information System (GIS). This module allowed us to find the shortest route for a series of defined destinations considering the route barriers and other constraints, such as speed limits. Further, the fuel consumption of each truck was calculated on the optimized route and compared with the normal route. To calculate fuel consumption, the Council's data sheet on fuel usage was used as entry data. Finally, the study compared fuel consumption and GHG emission rate of the selected trucks on their optimized route and usual route.

Waste Management

Waste management is a vast industry with many relevant sub-sections. Therefore, there are various methods to reduce GHG emissions in the sector. These methods range from reducing waste to reusing, recycling, and landfilling it. According to the agreement with Blacktown City Council (Attachment 1), this study focused on reducing waste at its origin. Thus, it selected two case studies of the Council: a library and an aquatic center and investigated different techniques to reduce general waste in each one.

The methodology used in this part includes waste audits in each center, categorizing the waste, weighting each category, and proposing some practical solutions to reduce general waste. The waste stream was classified into recycling, composting, and general waste and the quantity of each category was measured. Based on the waste flow in each section and the type of waste, the study proposed a solution to mitigate the general waste stream.

Urban Land Use

This section investigated various methods to reduce the Heat Islands Effects to develop a resilient city. According to the agreement with Blacktown City Council (Attachment 1), this study selected one of the main streets of the Council as the Case study.

To investigate the effects of cooling street strategies on the Urban Heat Islands, the study used the ENVI-Met microclimate simulation model. It entered the baseline of the climatological parameters into the ENVI-Met model and calibrated the model using the actual weather data of the region. Finally, it run the model with the simulated cooling street strategies. The study analyzed the effects of these strategies on the street temperature in the next stage by comparing the various climate parameters in the base line scenario with the simulated cooling street scenarios. These scenarios include tree planting and cool pavements.

Energy Management

Energy efficiency is another significant method to reduce GHG emissions, and thereby, the GHG emission of the Council. As per the agreement with Blacktown City Council, this study investigated the various energy efficiency strategies adopted by the Council from 2008 to 2016 to reduce the Council's total emission. Therefore, this part of the study only investigated earlier actions of the Council to reduce energy consumption and emissions and analyzes them in terms of emission reduction rate, returning period, and actual cost.

This study used the Planet Footprint company energy data gathered for the Council from 2008 to 2016. It then investigated their GHG emission reduction potential using the relevant formula, calculate the returning period, capital, and ongoing cost. In the last stage, these innovative practices compared together and the most and the least efficient solution were introduced.

4. Thesis Structure

This thesis has eleven chapters as follows:

1- Introduction
2- Overview of the International Carbon Reduction Toolkit
3- Case study and the Main Source of Data
4- Materials and Methods
5- GHG emission reduction in Transportation
6- GHG emission Reduction in Waste Management
7- GHG emission Reduction by Managing the Urban Land Use
8- GHG emission Reduction by Increasing Energy Efficiency
9- GHG Emission Reduction Toolkit
10- Key Recommendation for Using the Toolkit
11- Conclusion

The ***Introduction chapter*** contains the background of climate change and the global, national, and local efforts to reduce it. Next, it discusses the main objective of this research study and its cross-connection with the local and national policy document. Finally, it presents a summary of the methodologies in each section.

Chapter 2 takes a look at the international carbon reduction toolkit. The main aim of this chapter is to provide an overview of the available toolkits around the world, analyses them, compares them, and extracts their focus for this research study. This chapter is the core of this study, as it determines the main criteria of research.

Chapter 3 introduces the case study and presents the main source of data. The chapter takes a look at the environmental plans and policies of Blacktown City Council as the Case study of this research study. In addition, it introduces the cross-connection between the Council's plans and policies with this research project.

Chapter 4 introduces the applied methodologies in the study. Firstly, it explains the necessity of a GHG emission reduction toolkit in an urban scale, then the procedure of structuring the kit and its main elements are introduced. Finally, a snapshot on the applied methods for piloting the tools are presented and their linkage illustrated using a road map of applied methodologies.

Chapter 5 introduces the GHG emission reduction strategy in transportation, which is in the line with the research area of this study. Note that the proposed strategy is not a comprehensive transportation toolkit, but aligns with the objectives of this thesis. This chapter presents the fuel consumption rate of the heavy vehicles and introduces the smart solution to reduce this rate. In particular, this chapter focuses on the effects of route optimization to reduce the GHG emissions of heavy-vehicles.

Chapter 6 introduces some proposed strategies for GHG emission reduction in waste management. In particular, it investigates cost-efficient solutions for reducing GHG emission from general waste by decreasing waste at the origin point. Furthermore, this chapter proposes a waste management plan for the Council highlighting issues, actions, policy type, and resources required for undertaking action.

Chapter 7 analyzes strategies for GHG emission reduction by managing urban land use. In particular, it investigates two main strategies for reducing heat islands: tree canopy cover and cool pavement. This chapter compares these two street cooling strategies in terms of their potential for temperature reduction. Finally, this chapter proposes the best combination of cooling street strategies matched to the case study.

Chapter 8 analyzes the strategies for GHG emission reduction by lowering the energy consumption. It introduces the energy efficiency initiatives undertaken by the Council from 2008 to 2016, compares them in terms of energy efficiency, payback period, and total required capital. Finally, it introduces a combination of energy reduction strategies to be matched to the Council's assets.

Chapter 9 as the heart of this thesis, introduces the GHG emission reduction toolkit in four pre-defined categories. This chapter summarizes the carbon reduction strategies of other chapters, and takes a step forward to present a comprehensive GHG mitigation toolkit by reviewing the associated literature.

Chapter 10 presents the key recommendations for using the introduced toolkit in chapter 9. This chapter introduces the international implications of this research study and its applicability in other regions. in addition, it explains the significance of community engagement in the toolkit's planning and implementation process. Also, it describes the process toward delivering a policy framework for execution of the toolkit and presents a monitoring and evaluation plan for assessing the toolkit's implementation process.

Chapter 11 wraps up the thesis and summarizes its main findings, along with suggestions for new studies in this field.

CHAPTER 2

Overview of the International GHG Emission Reduction Toolkits

SUMMARY

This chapter introduces and evaluates 20 major international GHG emission reduction toolkits at city level, according to their sustainability coverage and their features. The features examined in this chapter are transportation, infrastructure, ecology, resources, energy, community, location, economy, and building.

This chapter also feeds the next phase of this study in choosing the most influential criteria to be worked on.

1. Introduction

Before proceeding to design any toolkit for GHG emission reduction an overview of the available global toolkits is required. However, despite many toolkits being available at the building level for reducing carbon emission, very few toolkits are available for the city or neighborhood level. Many studies have attempted to reduce GHG emission in the design, construction, and demolition phases of a building; however, this number is very low at the urban planning and neighborhood level. A review of the literature is presented in this chapter to show the associated resources. In this chapter, the available global toolkits was examined, their primary factors were extracted and compared, and the most suitable factors were investigated.

Low carbon neighborhood is broadly defined as being moderately dense, mixed-use, designed at a human scale, active and public transportation oriented. The emphasis is on sustainable transportation and proximity to diversity of services and amenities (H. Li & Liu, 2016; Saito, Said, & Shinozaki, 2017). In short, these elements make neighborhoods livable places (Denis-Jacob, 2011).

With this new concept of low carbon neighborhood, the need for assessing a neighborhood according to its rate of greening has become an issue for consideration (Karimipour, Mojtahedi, & Azari Dehkordi, 2015). Recent literature has discussed the importance of assessing sustainable development at the community and neighborhood scales (Berardi, 2011; Turcu, 2012).

The important point is that a framework is required to evaluate objectives and strategies of sustainable community development (M. G. Lee & Kim, 2016; Yuqin Liu et al., 2015). These must result in the emergence and spread of certification systems. Considering the variety of objectives, strategies, and practical approaches of sustainable development at different levels and in areas, it can be stated that “certification systems” are frameworks for assessing these objectives and approaches at the city scale (Hamedani & Huber, 2012; Sharifi & Murayama, 2013). The low carbon neighborhood toolkits were first designed in Europe and North America and then spread globally.

A low carbon neighborhood toolkit evaluates the sustainability performance of a given neighborhood against a set of criteria (Sharifi & Murayama, 2013). According to the classification by Sharifi and Murayama (2013), there are two types of neighborhood sustainability assessment toolkits: decision making tools embedded into neighborhood scale planning (e.g., HQE2R, Ecocity, EcoDistricts, SPeAR, One Planet (Communities) Living, EcoDistricts Performance and Assessment Toolkit), and the systems created from existing third-party building assessment systems. (e.g., LEED (ND), BREEAM (Communities), CASBEE (For Urban Development), QSAS, Green Star (Communities), Green Mark for Districts, and Low carbon neighborhood Index (Reith & Orova, 2015). The full terminologies of 20 low carbon neighborhood assessment toolkits are shown in Table 2.

Table 2: International toolkits for assessing the low-carbon neighborhood and their specifications

Row	Abbreviation	Full terminology	First version year	Last version year	Number of indices	Country	Institution	Verification fee (USD)	Assessment period (month)	Number of certificate/ projects	Link to the website
1	**LEED (ND)**	Leadership in Energy and Environmental Design	2009	2016	56	US	United States Green Building Council	30000-47000	40-100 days	184	http://www.usgbc.org/LEED
1	**LEED (ND)**	Leadership in Energy and Environmental Design	2009	2016	56	US	United States Green Building Council	30000-47000	40-100 days	184	http://www.usgbc.org/LEED
2	**DGNB**	Deutsche Gesellschaft für Nachhaltiges Bauen	2008	2012	36	GR	German Sustainable Building Council	5000-118000	5	39	http://www.dgnb-system.de/dgnb-system/en
3	**CASBEE** (urban development)	Comprehensiv e Assessment System for Building Environmental Efficiency	2006	2014	30	JA	JSBC (Japan Sustainable Building Consortium), Institute for Building Environment and Energy Conservation (IBEC)	16300-25100	6-12	4 Projects	http://www.ibec.or.jp/CASBEE/english/overviewE.htm
4	**BREEAM** (communities)	Building Research Establishment Environmental Assessment Method	2008	2012	40	UK	BRE Global Ltd	_	_	_	https://www.breeam.com/discover/technical-standards/communities/
5	**Green Star** (communities)	_	2010	2012	38	AU	Green Building Council of Australia	25800-40000	6-10	_	http://www.gbca.org.au/green-star/green-star-communities/
6	**STAR** (community rating system)	Sustainability Tool for Assessing and Rating communities	2012	2015	48	US	Star Communities non-profit organization	1500-7500	2	50	http://www.starcommunities.org/rating-system/
7	**Envirodevelopment**	_	2006	2014	117	AU	Urban development	3000-17500	12	100	http://www.envirodevelopment.com.au/

Row	Abbreviation	Full terminology	First version year	Last version year	Number of indices	Country	Institution	Verification fee (USD)	Assessment period (month)	Number of certificate/ projects	Link to the website
							institute of Australia (Queensland)				
8	**One Planet** (communities)	_	2003	2015	_	UK	BioRegional Development Group and WWF International	_	3	11	http://www.bioregional.com/
9	**BCA** (Green Mark for District)	Building and Construction Authority	2009	2013	38	SG	Building and Construction Authority	2450-18700	_	_	https://www.bca.gov.sg/green_mark/
10	**Green Townships (IGBC)**	Indian Green Building Council	2010	2015	26	IN	Indian Green Building Council	1450-3450	_	_	https://igbc.in/igbc/
11	**QSAS/ GSAS**	Qatar/Global Sustainability Assessment System	2010	2015	39	QT	Gulf Organization for Research and Development	700-1400 reg. fee+ $0.05/m2 + $550 Appeal fee	_	_	http://www.gord.qa/gord-trust
12	**Pearl Community rating system**	_	2010	2010	64	UAE	Abu Dhabi Urban Planning Council	_	2	_	http://estidama.upc.gov.ae/?lang=en-US
13	**Neighbourhood Sustainability Framework**	_	2007	2014	23	NZ	Beacon Pathway	_	_	18	http://www.beaconpathway.co.nz/
14	**EcoDistricts (**Performance and Assessment Toolkit**)**	_	2011	2016	95	US	Portland Sustainability Institute	_	12	16	https://ecodistricts.org/
15	**Green Infrastructure** (project)	_	2012	2014	35	AU	Department of Environment, Water and Natural Resources	_	_	1 project	http://gievidencebase.botanicgardens.sa.gov.au/
16	**EcoCity**	_	2005	2012	41	EU	European Commission, DG Research	_	_	3 communities	http://www.ecocity-project.eu/
17	**HQE2R**	High Quality Environment and Economy	2004	2004	51	EU	European Commission (France)	_	The Project took	14	http://www.suden.org/en/european-projects/the-hqe2r-project/

Row	Abbreviation	Full terminology	First version year	Last version year	Number of indices	Country	Institution	Verification fee (USD)	Assessment period (month)	Number of certificate/ projects	Link to the website
		in Regeneration							about 40 months		
18	**EarthCraft Communities**	_	2005	2014	74	US	EarthCraft, Greater Atlanta Home Builders Association, Southface	_	_	_	http://www.earthcraft.org/builders/programs/earthcraft-communities/
19	**GCAP**	Green City Action Plan	2014	2014	15	MY	Asian Development Bank	_	_	_	http://www.melakagreentech.gov.my/
20	**SPeAR**	Sustainable Project Appraisal Routine	2000	2012	15	UK	ARUP	_	_	100	http://www.arup.com/

Despite possessing the world's biggest construction industry, China has no certification system for assessing low carbon neighborhoods. However, at the national level, the National Development and Reform Commission (NDRC) in China announced five provinces and eight cities to pilot low carbon development in August 2010. The five provinces are Guangdong, Liaoning, Hubei, Shanxi, and Yunnan. The eight cities are Tianjin, Chongqing, Shenzhen, Xiamen, Hangzhou, Nanchang, Guiyang, and Baoding. In February 2011, the NDRC required the five provinces and eight cities to include low-carbon development models in their regional 12th five-year plans. This shows China's commitment to introducing a national low carbon neighborhood system (Consulate General Shanghai, 2011).

2. Applied Methods for Evaluating A GHG Emission Reduction Toolkit

Sustainability assessment is regarded as the latest generation of impact assessment tools, and can be defined as "any process that directs decision-making towards sustainability" (Bond, Morrison-Saunders, & Pope, 2012). Ambiguities in the definition of sustainable development are also reflected in the definition of its assessment (Berardi, 2013; Ness, Urbel-Piirsalu, Anderberg, & Olsson, 2007). Numerous methodological approaches have been taken to assess sustainability. All these approaches use indicators as tools for generating usable and relevant information from the increasingly expanding volume of data that they acquire from a wide array of sources (Mitchell & Gordon, 1996). A plethora of research exists on the principles and indicators of sustainable urban and neighborhood development (Sharifi & Murayama, 2015).

Low carbon assessment toolkits are compared based on the sustainability framework reflected in their indicators and main topics (Yang, Sun, Ge, & Li, 2017). For this purpose, and because of the complexities in analysis and the systems based on sustainability, the comparison is on two levels: (1) sustainability coverage or theme-based comparison and (2) feature-based comparison. The first type of comparison is useful for those who are interested in the concept of sustainable cities and its specifications or for comparing the systems based on the sustainable development approaches; however, the second type of comparison is helpful for those who want to apply their communities for inclusion in each system. This part of the thesis indicates the information that these communities may need before inclusion and as a snapshot for comparison. The following section describes these two types of comparison and the comparison methodology.

A set of viewpoints for comparison are defined based on the existing literature (Haapio, 2012; Haapio & Viitaniemi, 2008; Kyrkou & Karthaus, 2011; Sharifi & Murayama, 2013) to synthesize currently available data in existing studies and supplement them with new findings. The selected low carbon assessment toolkits are then evaluated according to the defined viewpoints. These defined viewpoints included: theme-based comparison and feature-based comparison (region, time, cost, and number of projects). the steps of the evaluation methodology and the connections between the phases is presented in Figure 3. The general comparison started with the collection of a list of properties from each low carbon neighborhood assessment system (Table 2).

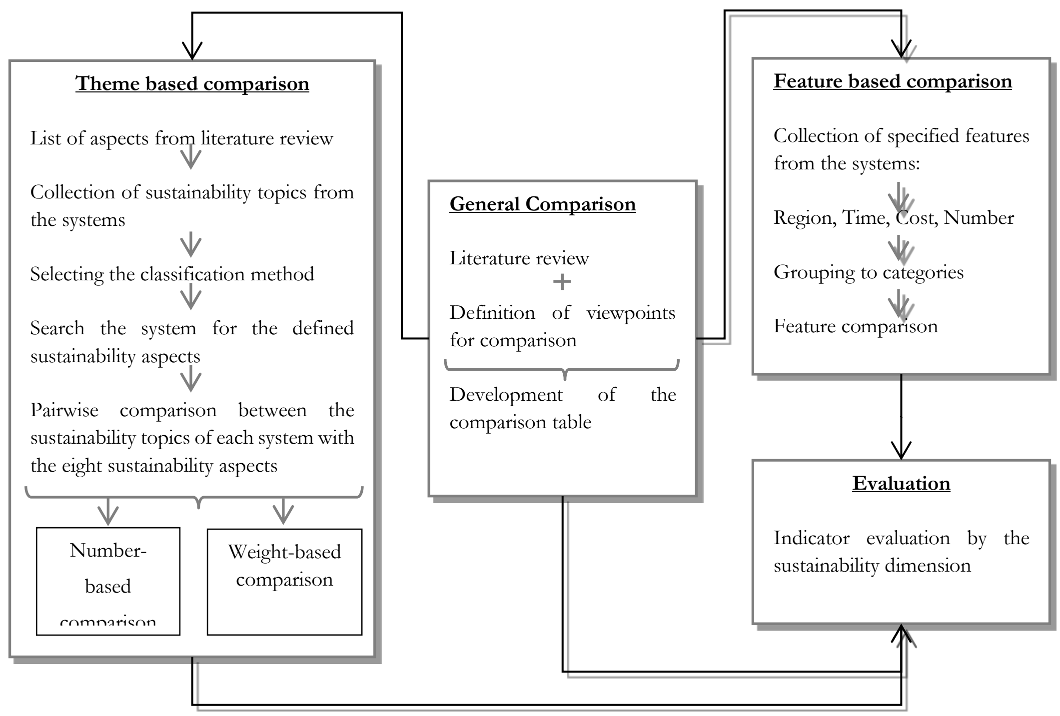


Figure 3: Five simplified steps of the novel analysis of the international low carbon neighborhood assessment toolkits

As Figure 3 shows, statistics were gathered around each assessment system, including: first version, last version, main aim, type of space included, number of items, country, institution, verification fee, assessment time, number of certification/projects, link to the website and period of validity of certification. For this purpose, the manual/guideline of each assessment system was downloaded and summarized in Table 2; however, when the required data was not available in the guideline, it was obtained from the system coordinator (although, in some cases, there was no reply, and these fields remained empty in Table 2). The resources used to create the table are from each assessment system's manual or guideline, which was included (Abu Dhabi Urban Planning Council, 2010; ARUP, 2012; Asian Development Bank, 2014; Beacon Pathway, 2014; BioRegional Development Group and WWF International, 2015; BRE Global Ltd, 2012; Building and Construction Authority, 2013; EarthCraft Greater Atlanta Home Builders Association Southface, 2014; Ely & Sheryn, 2014; European Commission, 2004; European Commission DG Research, 2012; German Sustainable Building Council, 2012; Green Building Council of Australia, 2012; Gulf Organization for Research and Development, 2015; Indian Green Building Council, 2015; Japan Sustainable Building Consortium, 2014; Portland Sustainability Institute, 2016; Star Communities non-profit organization, 2015; Urban development institute of Australia, 2014; US Green Building Council, 2016).

2.1. Theme-based Assessment (sustainability coverage)

The frameworks of each system tend to be organized in different ways making the analysis of scope difficult. Haapio and Viitaniemi (2008) noted that the complexity of framework and their different structures might make them impossible for comparison. For instance, LEED (ND) has five themes, while Green Star (Communities) has six themes and SPeAR has 23. Similarly, criteria within themes are described and grouped differently (Sullivan, 2014).

Fortunately, the main The theme in each system shows the main topics concerning the system, while the index group is about the strategy or solution they choose for each topic and indicator related to the in-detail specifications of each strategy. The indicator shows the most detailed view of each system, which collects and evaluates the core components of the sustainability assessment tools.

Because of the topic variation, index, and indicator levels in each system, prior literature often used the theoretical benchmarks of ideal sustainability to compare system frameworks. However, this also varies with personal interests. In particular, sustainability coverage is often compared to a set of themes: W. L. Lee (2013) developed ten principles for sustainable neighborhood development; Hamedani and Huber (2012) identified eight criteria in their comparison; Haapio (2012) and Chandratilake and Dias (2013) used seven criteria and Reight and Orova (2015) used nine main categories for their comparison. This makes reviewing their results problematic, as studies may not be comparing them in similar contexts (Sullivan, 2014). However, among these studies, Reith and Orova (2015) were closer to the aim of this research, as they focused on the sustainability aspects of low carbon neighborhood and were also more up-to-date than other studies. This study uses their topic classification, as they categorized all the themes of all low-carbon neighborhood assessment toolkits into nine aspects, as shown in **Error! Reference source not found.**

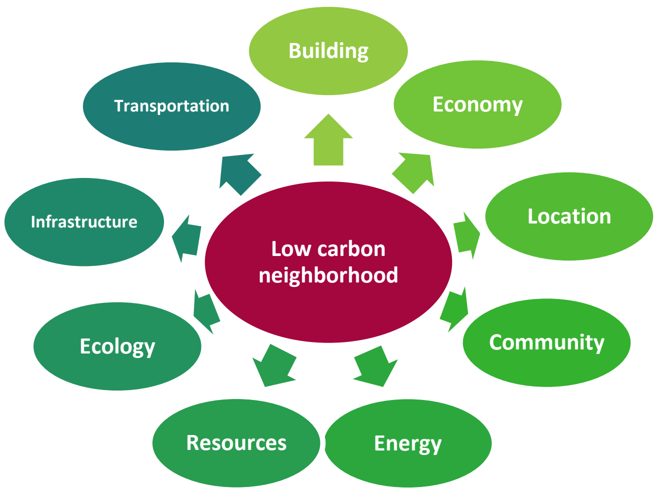


Figure 4: Sustainability framework classifications to be used for assessing low carbon neighborhood assessment toolkits

Therefore, for the theme-based comparison and on the basis of the categories mentioned above, the relation of the systems main topics to the different aspects of sustainability becomes evident. For this purpose, a pairwise comparison among these nine aspects of sustainability framework was conducted.

A weighted comparison was also undertaken to show the number of each sustainability aspect into the low-carbon neighborhood assessment toolkits, and their weightings as an indicator for their importance. The scoring methods used for weight-based comparison are straightforward, as shown in Equation 1.

$$\boldsymbol{Weighted\ Theme\%} = \frac{\sum Weight\ of\ theme\ in\ any\ system\ which\ have\ it}{\sum All\ the\ weights\ in\ all\ systems} \times 100$$

Equation 1

2.2. Feature-based Assessment

Many communities are beginning to recognize the impacts of their neighborhoods on the environment and make significant changes for mitigating environmental impact (Schüle, Gabriel, & Bolte, 2017; Seiferling, Naik, Ratti, & Proulx, 2017). This shift in attitude has been driven largely by a growing market demand for environmentally sound and energy efficient products and services, initiated primarily from the non-profit sector and federal, state, and municipal building projects (GhaffarianHoseini et al., 2013). A central issue in striving towards reduced environmental impact is the need for an applicable and meaningful yardstick for measuring environmental and energy performance (Smith, Fischlein, Suh, & Huelman, 2006).

Some systems and mechanisms have been developed worldwide to help decision makers and communities assess their actual impacts on the environment, as summarized in Table 2. These systems differ in sizes, reputation, years of publication, topics used, and fees. Therefore, this section illustrates these types of diversities.

The features under comparison in this section are as follows: region or country of location, cost of assessment or receiving certification, number of certificates/projects under each system, and the first year of appearance of each system. This information is obtained from at least 60 resources, and may be useful for communities interested in assessing their environmental impacts and obtaining certificates.

3. Results of Assessing the Carbon Reduction Toolkits

3.1. General Assessment

The general assessment results are summarized in Table 2. The general comparison shows basic information about the systems. Furthermore, reflects the method of certification for the green neighborhood assessment toolkits, and provides information on some specifications of each system. A list of 20 main green neighborhood systems around the world has been summarized.

The main aim of each system and the type of space included are summarized in Table 3. The space included in each system varies in sizes and types. For example, while the Building Codes of Australia require at least 20 ha of space to consider a region a green neighborhood, Green Star (communities) requires that the proposed neighborhood should include at least four buildings in any sizes. SPeAR, on the other hand, covers all forms of projects, including the design and delivery of new infrastructure, master plans, and individual buildings.

Table 3: Main aim and type of space included in the international green neighborhood assessment toolkits

Row	System	Main aim	Type space included
1	Green Infrastructure	The Green Infrastructure Project, hosted by the Botanic Gardens of South, has developed an evidence base for Green Infrastructure in South Australia. The vision of this Project is "South Australians living in healthy, resilient and beautiful landscapes that sustain and connect people with plants and places."	_
2	EcoCity	EcoCity Project was designed to minimize the use of land, energy and materials, minimize the impairment of the natural environment, maximize human well-being, and minimize transport demand.	All uses in the area of a city
3	Green Townships	IGBC Green Townships Rating System is designed to address the issues of sprawl, automobile dependency, social and environmental disconnect.	At least 25% of the total built-up area (in sq. m.) within the township should be earmarked for residential use.
4	HQE2R	HQE2R was designed to provide an integrated approach with adapted methods and tools for use by local municipalities and their	_

Row	System	Main aim	Type space included
		partners in their neighborhood regeneration projects, as in urban management projects.	
5	**EarthCraft Communities**	EarthCraft Communities (ECC) is a developer-certified, third-party verified program that recognizes responsibly designed and constructed communities. It is a regionally specific tool utilized by land developers and local government agencies to promote smart growth, sustainable land development practices, and healthier communities.	The proposed ECC development must qualify as an infill location with walkable pedestrian connections to an existing sidewalk network.
6	**GSAS**	The primary objective of GSAS is to create a sustainable built environment that minimizes ecological impact while addressing the specific regional needs and environment of Qatar.	Newly developing and existing neighborhoods. Any combination of buildings can be assessed; there are no minimum or maximum sizes.
7	**Neighborhood Sustainability Framework**	The neighborhood-built environment is designed, constructed and managed to develop neighborhoods that are adaptive and resilient places. They allow people to create rich and satisfying lives while respecting the limitations of the natural environment.	Can be applied to both new and existing neighborhoods, planned new neighborhoods and neighborhoods about to be built.
8	**GCAP**	The GCAP provides a set of recommendations that are aimed at maintaining Melaka's competitiveness as a popular tourist and investment destination, keeping environmental challenges to a minimum, and establishing the state as a role model for livability in the region.	Just Maleka state (1663 Km2)
9	**BCA**	The BCA Green Mark Scheme was launched to promote environmental awareness in the construction and real estate sectors. It is a benchmarking scheme that aims to achieve a sustainable built environment by incorporating best practices in environmental design and construction, and the adoption of green district technologies.	>20 ha
10	**Pearl Community rating system**	The main aim of the Pearl system is to create more sustainable communities, cities, and global enterprises and to balance the four pillars of Estidama: environmental, economic, cultural and social.	At least 1000 permanent residential population
11	**EcoDistricts**	To foster a new model and era of urban regeneration, EcoDistricts has created the EcoDistricts Protocol, a framework for achieving people-centered, economically vibrant, planet-loving neighborhood- and district-scale sustainability.	Existing neighborhood, Brownfield site, Business district, Institutional campuses, Industrial lands, Mixed-used district
12	**One Planet** (Communities)	One Planet (Communities) Living is an initiative of Bioregional and its partners to make truly sustainable living a reality. One Planet (Communities) Living uses ecological footprinting and carbon footprinting as its headline indicators.	Determined in each specific project
13	**SPeAR**	Arup has developed SPeAR® as a tool to assist in the consideration sustainability issues, particularly with regard to decision-making and communication with stakeholders.	SPeAR® is designed to cover all forms of projects, including the design and delivery of new infrastructure, masterplans, and individual buildings.
14	**Envirodevelopment**	Envirodevelopment is a scientific branding system designed to make it easier for purchasers to recognize, and thereby, select more environmentally sustainable homes and lifestyles.	From single detached houses to whole suburbs, with a CityCat terminal in between
15	**STAR**	The STAR Community Rating System (STAR) is a certification program to recognize sustainable communities. Local leaders use STAR to assess their sustainability, set targets for moving forward, and measure progress along the way.	_

Row	System	Main aim	Type space included
16	**Green Star** (Communities)	The Green Star (Communities) evaluates the sustainability attributes of the planning, design, and construction of large-scale development projects, at a precinct, neighborhood, and/or community scale	A project's plan for development must include the development of at least four (4) buildings, of any size and mixture of Class 1-9 structures (except Class 4), as classified under the Building Code of Australia (BCA).
17	**BREEAM (**Communities)	BREEAM (Communities) aims to ensure that its standards provide social and economic benefits whilst mitigating the impacts of the built environment. In doing so, BREEAM (Communities) enables developments to be recognized according to their sustainability benefits and stimulates demand for sustainable developments.	More useful for moderate or large mixed-use development; however, in some cases, it can be used for single development too.
18	**CASBEE** (For urban Development)	CASBEE aims for the comprehensive assessment of environmental performance of a construction project planned and conducted under the unified intention of development for a relatively large group of land sections, such as a whole block or a district consisting of blocks.	- A single block consisting of multiple building sites and public space adjacent to the block, such as a road. - Multiple collective blocks and public space existing integrally with them, such as roads.
19	**DGNB**	The DGNB assesses buildings and urban districts, which demonstrate an outstanding commitment to meeting sustainability objectives. This considers the following fields: Environmental Quality, Economic Quality, Sociocultural and Functional Quality, Technical Quality, and Process Quality. Site Quality is integrated here as a criterion for assessment.	1- The minimum size of an urban district is 2 ha of gross development area (GDA). 2- The district consists of several buildings and at least two development sites and has public or publicly accessible spaces and related infrastructure. 3- The residential is no less than 10% and no more than 90%.
20	**LEED (ND)**	LEED (ND) for Neighborhood Development (LEED (ND)) was engineered to inspire and help create better, more sustainable, well-connected neighborhoods. It looks beyond the scale of buildings to consider entire communities.	Designed for neighborhood-scale projects that are near completion, or were completed within the last three years.

The main aim of each system is similar, to create a sustainable built environment that minimizes ecological impact while addressing the specific needs of residents and the region.

3.2. Theme-based Assessment

The results of the comparison are summarized in **Error! Reference source not found.**. Owing to the multitude of systems, it was not possible to list the main topics of each assessment system individually; therefore, they have been summarized according to the nine sustainability topics shown in Figure 5.

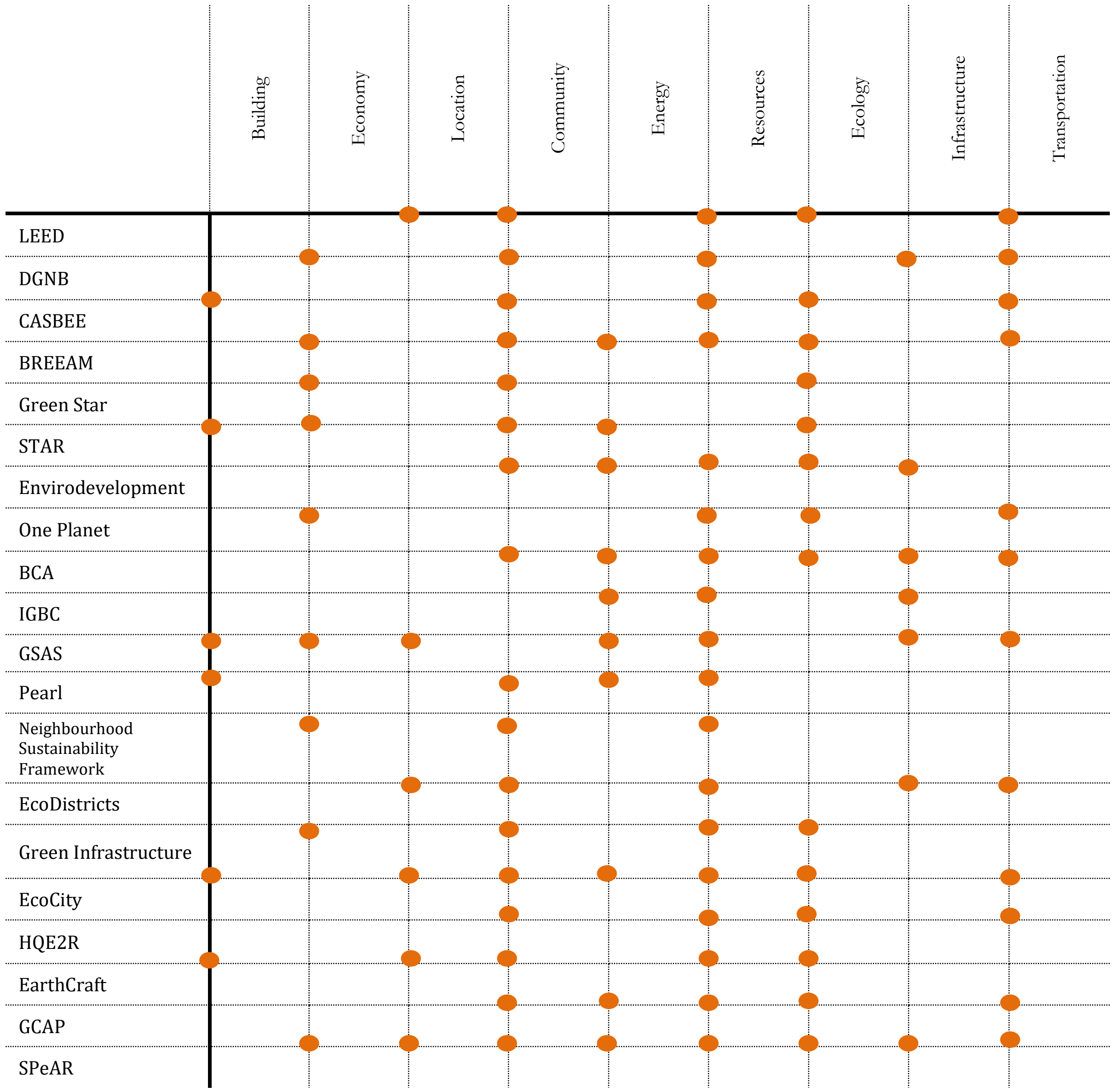


Figure 5: Sustainability coverage of 20 main low carbon neighborhood systems around the world

To prepare Figure 5, main topics and some sub-categories of each system were considered and pairwise comparison of the sustainability aspects and main topics or sub-topics of each system was conducted, as shown in Figure 6. It is found that ecology, resources, and community acquire the most number allocated by the systems. Thus, community has been repeated in 18, resources 17, and ecology 16 times out of 20 systems, which demonstrates their importance in the green neighborhood assessment frameworks. In addition, location, infrastructure, and building with number of repetitions of 6, 7, and 8, respectively, stayed on the lowest positions. The other sustainability aspects had average repetition between these two peaks.

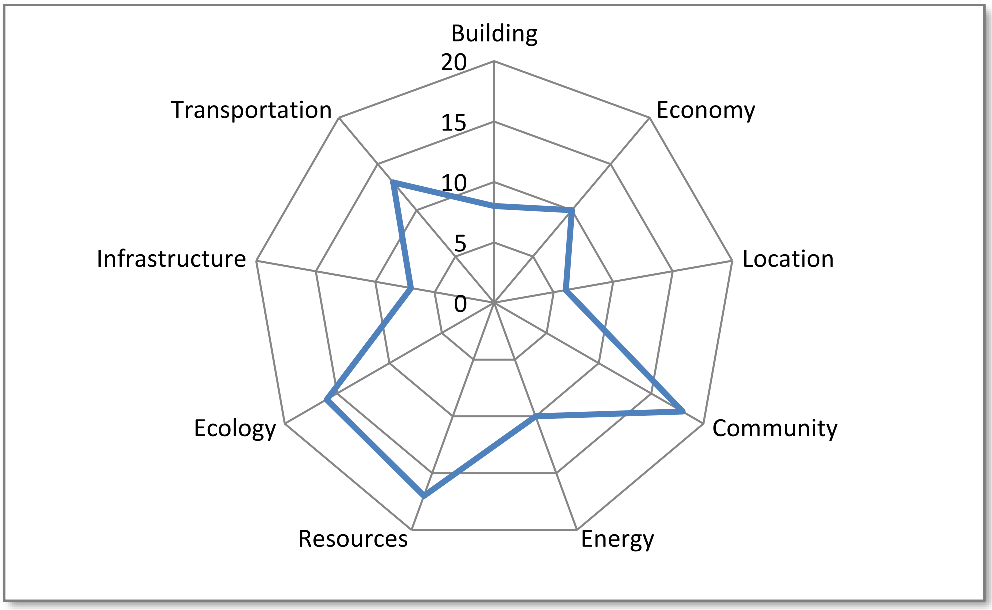


Figure 6: Sustainability aspects of the low-carbon neighborhood assessment toolkits

This comparison shows that some assessment toolkits considered additional sustainability aspects than other systems. Some of these systems are designed for only temporary or specific use, such as green infrastructure projects. The botanic gardens of South Australia cover only four sustainability aspects; however, GSAS, which expects to be applicable for all low-carbon neighborhood systems around Qatar or even Middle East regions, covers seven sustainability aspects.

Another major difference among systems is not only the number of sustainability aspects considered, but also the weighting they allocate to each of their main topics or sustainability aspects. From this perspective, some systems may consider certain aspects more important than they do others. The results of this weighting comparison are shown in Figure 7. The differences among sustainability aspects in Figure 6 decreased after their weightings. Economy, resources, transportation, energy, and ecology acquire the highest importance among the whole criteria. Alternatively, economy moves to the highest importance after its weighting. Therefore, the average of systems collects its higher weighting of importance. In addition, transportation and energy ascend to higher levels by their weightings, which demonstrate their importance in each system. In contrast, community obtains the highest repetition number in Figure 6, and descends to the average rate after considering its weighting, which shows its low weighting in the systems.

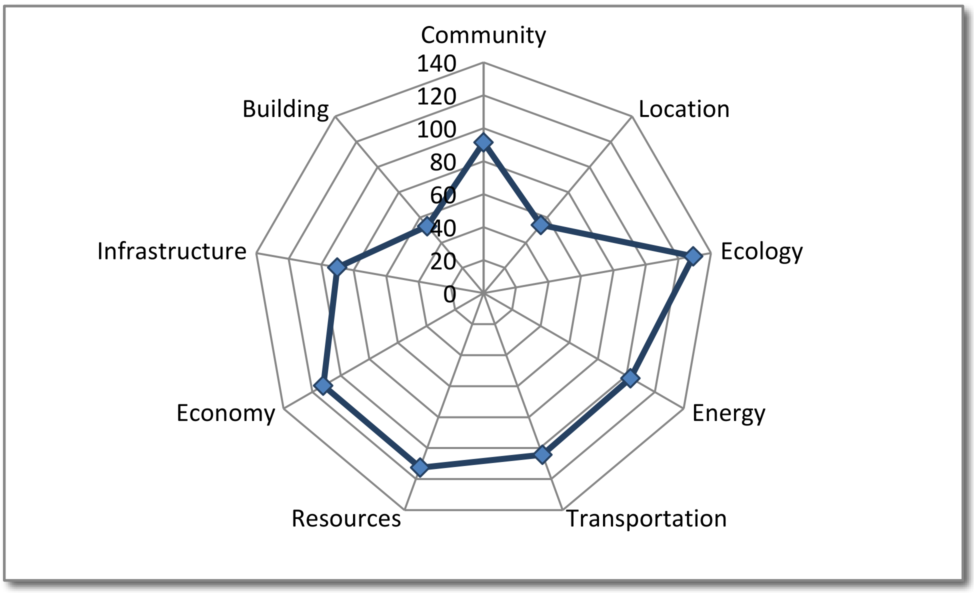


Figure 7: Weighted counts of sustainability aspects for low-carbon neighborhood assessment toolkits

3.3. Feature-based Assessment

In addition to describing and analyzing "a framework," research has also examined the other side of the assessment system, which analyzes "how a framework is used (Zuo & Zhao, 2014)?" This section reviews the regions where each system appears, time of appearance, costs of obtaining certificates, and the number of certificates/projects under each assessment system.

3.3.1. Distribution of low-carbon assessment toolkits around the world

Figure 8 shows 20 low-carbon neighborhood assessment toolkits distributed around the world. The United States with four assessment toolkits followed by the United Kingdom and Australia with three each have the most various frameworks in the world. In addition, Germany, Japan, Singapore, India, United Arab of Emirates, New Zealand, Qatar, and Malaysia have one framework each. In addition, the European Union introduced two mega projects, including Ecocity and HQE2R; both are decision-making tools for upcoming systems. Most of the systems around the world are in North America, Europe, and Oceania and some new systems have developed in Eastern Asia and the Middle East.

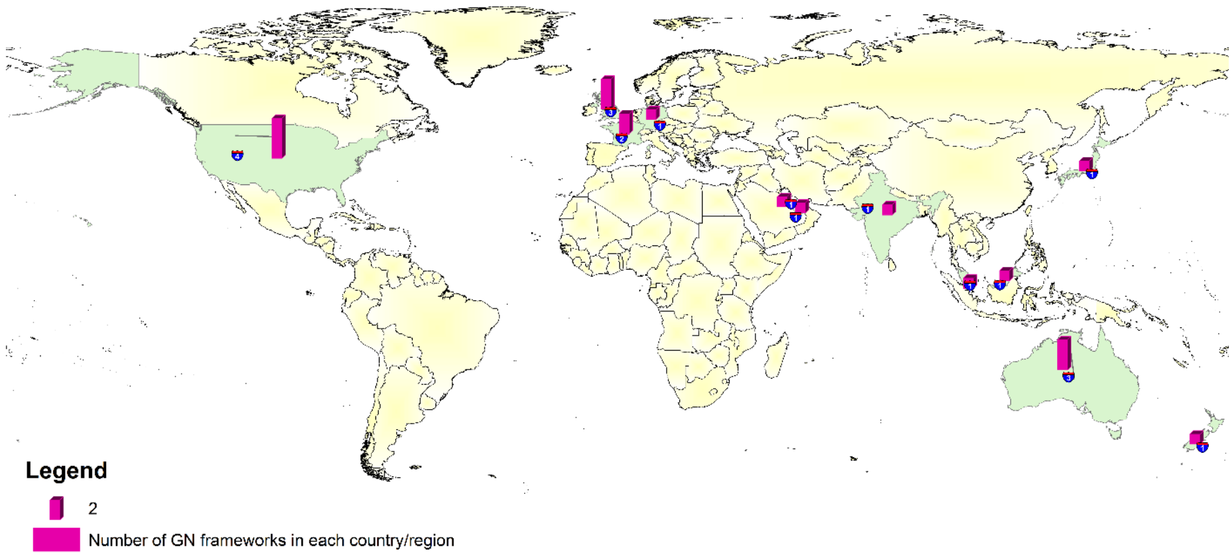


Figure 8: Number of low-carbon neighborhood assessment toolkits around the world

3.3.2. Lifetime of the low carbon assessment systems

The lifetime of the low-carbon assessment toolkits is an indicator of this emerging approach globally. The result of this part is summarized in Figure 9 and Table 4. The first systems on low-carbon neighborhoods were established in United Kingdom in 2000 and 2003. These systems were revised in future years; however, initially, they focused on a novel approach to communicating and delivering sustainability. As the first system, SPeAR was designed as a sustainability appraisal tool and a framework to support project development and communicate outcomes according to sustainable development aspects; however, One Planet (Communities), which is the second emerging system, mostly focused on implementing some low-carbon neighborhood practices around the United Kingdom.

Table 4: Life time of the low-carbon neighborhood assessment toolkits around the world

Year of first version released	Name of Systems	Country	Living time of the system (Year)
2000	SPeAR	United Kingdom	16
2003	One Planet (Communities)	United Kingdom	13
2004	HQE2R	European Union	12
2005	Earthcraft Communities, Ecocity	United States, European Union	11
2006	Envirodevelopment, CASBEE (For Urban Development)	Australia, Japan	10
2007	Neighbourhood Sustainability Framework	New Zealand	9
2008	DGNB, BREEAM (Communities)	Germany, United Kingdom	8
2009	LEED (ND), BCA	United States, Singapore	7
2010	IGBC, QSAS, Pearl, Green Star (Communities)	India, Qatar, United Arab od Emirates, Australia	6
2011	Ecodistrct	United States	5
2012	STAR, Green Infrastructure Project	United States	2
2014	GCAP	Malaysia	2

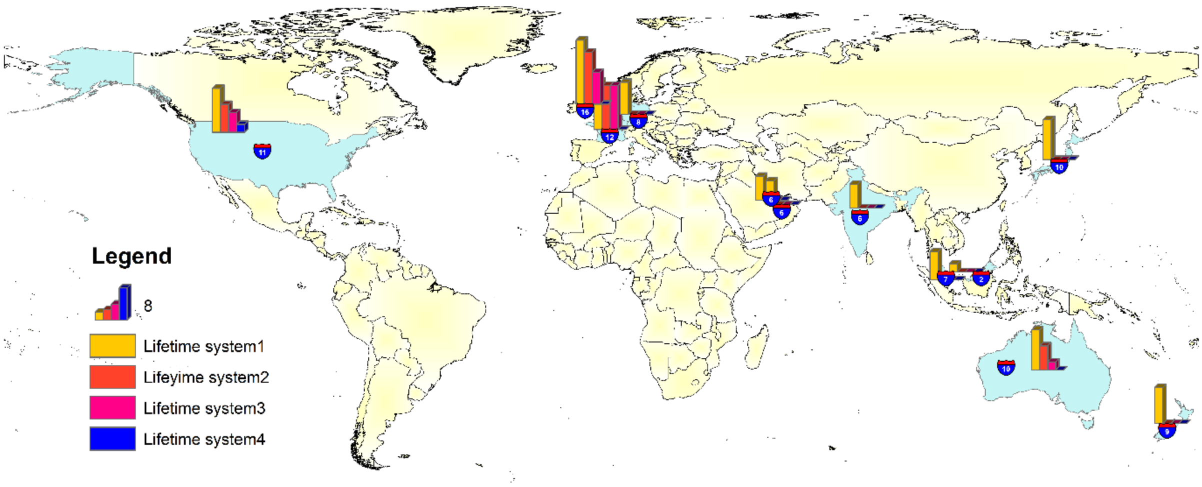


Figure 9: Lifetime of the low-carbon neighborhood assessment toolkits around the world

Subsequently, in 2004, HQE²R was invented in the European Union as a methodological framework for sustainable regeneration projects, reflecting the needs for these types of decision-making frameworks in urban development in Europe. Ecocity emerged in 2005 in the European Union, resulting from a new trend of sustainable cities on this continent. Emerging in 2005, Earthcraft (communities) was the first system in the world to focus on neighborhood assessment according to sustainability levels. However, it was a regionally specific tool utilized by land developers and local government agencies to promote smart growth, sustainable land development practices, and healthier communities.

CASBEE (For Urban Development), DGNB, BREEAM (Communities) and LEED (ND) were introduced between 2006 and 2009 as a result of the demand for sustainable city development and its appraisal system. This new approach reached Australia and New Zealand in 2006 and 2007 with Envirodevelopment and Neighborhood Sustainability Framework, respectively. The eastern part of Asia and the Middle East designed their own regional specific tools between 2008 and 2014, according to their particular requirements in sustainable urban development.

4. Research Gap, Significance and Contributions to This Research Study

As stated previously in the introduction, climate change is affecting all ecosystems in the world, including the human-builds' one. Cities are responsible for 70% of the total GHG emission (Leahy, 2018), making their role in the global climate change very significant. According to IPCC Paris Agreement 2015, Australia has committed to reducing its GHG emission level by 26-28% below the 2005 level (Australian Government, 2017). However, it entails a significant reduction in emission of all the major GHG emitters, including the Australian cities. But what contribution any town will have in the country's total emission and how much? What is the abatement potential of each new technology to present to the city planner and policymaker assisting them in placing the associated policies? How much each initiative contributes to the total GHG emission reduction? And the questions of these kinds underline the central concept of this study.

As previously explained and presented in the literature review, no such articulated literature was found at the time of initiating this research to provide a comprehensive tool for GHG emission reduction at the city level. For proving this claim, a universal literature review was undertaken by the author in a 20 years period, and its results were presented in chapter 8, Table 20. When this research began, the Australian Government requested all the councils countrywide to offer their ten-year GHG abatement programs, and there was no articulated research to assist them in this regard.

It was where this research study emerged with three precise approaches:

1- To assist a local council in a policymaking process. In this approach, this study puts a step forward to link academic research with a real problem on the field, and highlight the role of a local university in covering up a real practical issue on the ground.

2- To fill the research gap in the body of knowledge, to present a comprehensive toolkit for lowering GHG emission reduction potential at the city level. My studies show; although there are scattered researches to alleviate GHG emission at a city level, there isn't any universal study to put them all together in an integrated toolkit. This issue, caused, for example, a local council such as Blacktown in Australia, doesn't have access to a comprehensive, integrated toolkit representing the potentials of GHG emission reduction.

3- To pilot three introduced tools of the most significant sources of GHG emission at a city level. It was impossible to examine all the suggested tools for decreasing GHG emission and regionally calibrate them in a single study. Instead, this research study chose one initiative in each sector to test the proposed mechanisms and quantify them with the relative abatement potential.

5. Summary

The following is a summary of the results of analysis of the global toolkits for GHG emission reduction at the neighborhood level:

- Community, resources, and ecology are the top three sustainability aspects that applied in 18, 17, and 16 systems, respectively, out of 20.
- These three aspects have nearly the same importance in systems around the world.
- A review of these three sustainability aspects shows that they cover the three pillars of sustainability. The community returns to society, resources can indirectly return to the economy, and ecology refers to the environment.
- However, after weighting the sustainability themes in each system, the differences among the aspects were removed and they became closer to each other. In this new set, ecology, energy, transportation, resources and economy received the highest rate, and community dropped to a lower rate of importance.
- In this new set of significance, the environment pillar of sustainable development can easily be highlighted.
- Considering the regional distribution of systems around the world, the initiative of low-carbon neighborhood system first began in the United Kingdom and the European Union in 2000 and 2004, respectively. This trend reached the United States in 2005. Australia, New Zealand introduced their own systems in 2006 and 2007, respectively, and South East Asia and Middle East commenced their own regional systems between 2009 and 2014.
- The United States, with four main low carbon neighborhood systems, owns the largest number of assessment toolkits in the world, followed by the United Kingdom and Australia with three systems each, the European Union with two systems, and the other countries with one system each.
- On the number of certificates/projects, LEED (ND) with 184 certificates is the most well-known system in the world followed by Envirodevelopment in Australia and SPeAR in United Kingdom with 100 certificates/projects each.
- With regard to certification fees, there is a range in each assessment system to evaluate the communities based on their project sizes and types. However, the minimum certification fee for LEED (ND) is US$30,000 followed by Green Star (Communities) and CASBEE. The maximum evaluation fee is for DGNB followed by LEED (ND) and Green Star (Communities).

This chapter overviewed the available global GHG emission reduction standards at a neighborhood level, extracted their main factors, and compared them in line with the research's objectives. This overview was significant before moving ahead to investigate the related toolkits and the available tactics in the literature. This overview helped me extract the most critical criteria for mitigating GHG emissions at the neighborhood level and making the toolkit structure. I became familiar with the major pillars of the available toolkits by looking at the global standards in the field and building the mainframe of this study. The main criteria for a green/ sustainable city and their average weightings are listed in Table 5.

Table 5: The main criteria for a green city and their average weightings

The main criteria of a sustainable city	The average weights in all systems
Community	91.5
Location	54
Ecology	129.1
Energy	103
Transportation	104.3
Resources	112.6
Economy	112.2
Infrastructure	90
Building	53

As this table shows, the main criteria for a sustainable city are community, location, ecology, energy, transportation, resources, economy, infrastructure and building. Affecting the criteria's average weighting in all systems, it is clear that ecology, resources, economy and transportation are the most crucial pillars of a sustainable city. These 4 criteria built the main structure of this study for developing a GHG emission reduction toolkit.

The results of this analysis show that ecology, energy, transportation, resources, and economy received the highest rating among the other criteria of low carbon neighborhoods. Since economy is out of the boundary of my expertise, It was removed from this research project. Therefore, this study investigates the following four main criteria of a low carbon neighborhood (Figure 10):

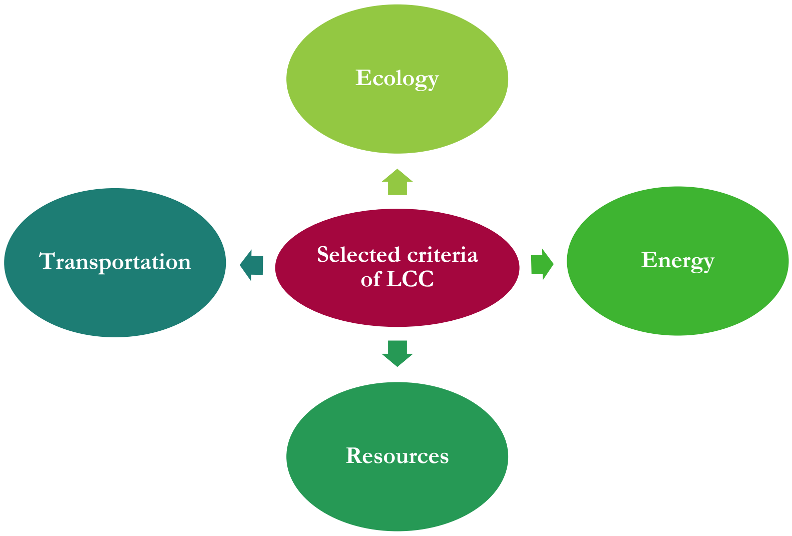


Figure 10: Selected criteria from low-carbon neighborhood investigated in this study

To refine the selected criteria to the requirements of the Blacktown City Council, we had a meeting on April 28, 2017. At this meeting, which included Ms. Vanessa Parkes, Ms. Donna Wallace, Dr. Helen Burnie, Prof. Vivian Tam and Hoda Karimipour, we agreed to the following main objectives for this research study. These themes are compatible with the selected criteria and of my literature review and the Council's demand:

- **For Ecology** the effects of urban land use management on reducing the heat island effects is investigated.
- **For Energy** the most cost-benefit solutions to increase the energy efficiency in the Council's buildings is investigated.
- **For Resource** the possible scenarios for reducing the GHG emission from the Council's waste is investigated.
- **For Transportation** the possible solution for reducing the GHG emission from the Council's fleet is investigated.

It should be mentioned that the main objective of this research study is to develop a toolkit for alleviating the GHG emission at an urban scale. To categorize this toolkit, and according to the literature review in chapter 2, the toolkit's four major parts were drawn up. Since it wasn't possible to quantify all the introduced tools in the toolkit, the panel decided to choose an instrument from each of the episodes, and pilot it in the Blacktown City. The question was which one of the introduced tools should be quantified and piloted?

The criteria for choosing the tool agreed to be: 1- the availability of the council's resources, 2- the council's priorities, and 3- the study's time frame. Considering all these criteria, the decision was made in a meeting on the 28th of April, 2017, and the four mentioned tools were selected for this study. The following documents have been prepared as the result of this meeting between Black town Council and Western Sydney University's authorities on April 28, 2017:

- A research collaboration agreement, which can be found in the Attachment 1.
- A research proposal, which can be found on page 248
- A letter of offer, which can be found on page 257

CHAPTER 3

Case Study and the Main Sources of Data

SUMMARY

This chapter introduces the Blacktown City Council, as the case study of the project. First, this chapter explains the Australian actions against climate change. In the next section, the steps taken by Blacktown City Council for climate change adaptation and mitigation is explained. This chapter also introduces and explains the Council's four major policies, which are Responding to Climate Change Policy, Integrated Transportation Policy, Urban Forest Policy, and Carbon Accounting Method.

1. Australia's Action against Climate Change

Australia has a naturally emission-intensive economy, with far higher emissions per capita than any other developed country (Wang et al., 2016). Most other developed countries now have falling or steady emissions; however, largely because of economic development, Australia's emissions continue to increase (Wang et al., 2016).

However, under the Paris Agreement, Australia has committed to reduce emissions by 26 to 28% below 2005 levels by 2030. This will see emissions per capita halved and the emissions intensity of the economy fall by around 65%. Across a range of indicators, this target is in step with other major developed countries such as the United States, the European Union, Canada, and New Zealand, and on a per capita basis, among the highest of major economies. In 2017, the Australian Government will review its climate policies and consider a potential long-term emissions reduction goal for beyond 2030 (Australian Government, 2017).

Australia's 2030 target builds on its 2020 target of 5% below 2000 levels, which it is on track to beat. Australia's official projections from December 2016 estimate it will over-achieve this target by 224 million tons of carbon dioxide equivalent (Mt CO_2-e). This follows from the Kyoto Protocol first commitment period (2008–2012) target, which Australia over-achieved by 128 Mt CO_2-e (Australian Government, 2016). Since the considerable part of Australia's emission comes from its commercial, residential, and transportation sector (Infrastructure Australia, 2010), it is clear that the most important part of Australian emission reduction must focus on its cities.

To reach its committed reduction levels by 26–28% below 2005 levels by 2030, all states and their subsidiary cities have begun developing mitigation policies and action plans, highlighting the measures necessary, time frame of each measure, its allocated budget, estimated level of GHG reduction, and the forecasted payback time.

2. Blacktown City

Blacktown City is the case study of this study. Blacktown is a modern bustling city of 48 residential suburbs, home to 350,000 people. It is the second largest local government area by population in New South Wales, Australia (Figure 11); 2.8% of Blacktown's residents are Aboriginal or Torres Strait Islanders. The city has people from 188 different birthplaces with the top five countries of origin being the Philippines, India, New Zealand, Fiji, and England. There are 182 languages spoken in Blacktown with the top five languages being Tagalog, Hindi, Punjabi, Arabic, and Filipino. The median age is 33 years; 22.8% are children aged between 0-14 years, while 20.2% are over 55 years old and 55.5% are families with children (Blacktown City Council, 2016a) .

Blacktown City acknowledges the Darug as the first people of the Blacktown region. The Darug people have lived in this region for thousands of years. This was a living country inter-twined and connected with the many clan groups of the Darug. The first European settlement was at the base of Prospect Hill in 1791. After the Second World War, the city's population of 18,000 began to grow, with housing development in Blacktown and along the railway lines. In the 1960s and 1970s, large-scale housing development took place in Blacktown and north of Mount Druitt. By 1981, the city was home to 181,000. Current growth is expected to continue with urban development focused in the North West Growth Centre, of which Blacktown local government area (LGA) has the principal share (Blacktown City Council, 2016a).

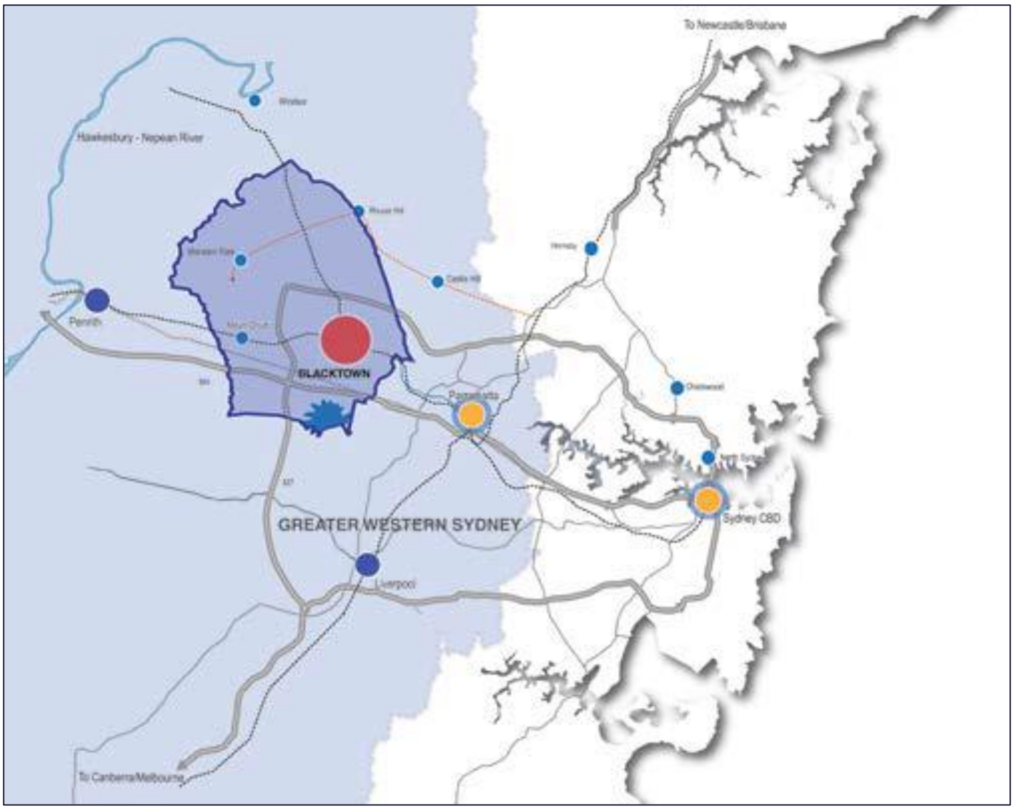


Figure 11: Location of Blacktown City in New South Wales (Wikipedia, 2020)

3. Blacktown City Environmental Plans and Policies

Blacktown City Council is committed to the conservation, restoration, and enhancement of the environment. In keeping with ecologically sustainable development principles, the Council works to balance social, economic, and environmental values and imperatives. Blacktown Council is working to rehabilitate the waterways, conserve and protect local bushland and wildlife, extend native habitat, improve air quality, and reduce waste and carbon emissions to provide a healthy environment for its residents today and in the future. Blacktown Council is committed to enhancing environmental awareness and engaging with the community to improve environmental outcomes. The Council works in partnership with the community, suppliers, and other stakeholders to progress toward sustainability (Blacktown City Council, 2016a). This journey involves striving to

- Protect and enhance biodiversity
- Reduce consumption of resources

- Take action to reduce waste and carbon pollution
- Engage with the community to support and encourage improved environmental outcomes.

Considering the expected outcomes of this research study, which is GHG emission reduction in transportation, resources, ecology, and energy, the Council's associated policies and plans were reviewed. As any suggested GHG emission reduction toolkit must align with the Council's policies and plans, these policies were reviewed, and summarized in the following sections.

3.1. Blacktown: Responding to Climate Change Policy and Strategy

To respond to climate change, the Council developed the Responding to Climate Change Policy and Strategy, which determines the policies, strategies, and actions to meet its commitments (Blacktown City Council, 2018a, 2018b). These commitments are as follows:

Policy commitment 1

Achieve net-zero emissions from the electricity, fuel, and gas we use in our operations by 2030.

Policy commitment 2

Adopt best practice to

a) *Mitigate the impacts of urban heat in our operations, own new assets and buildings, and when undertaking major facility upgrades*
b) *Minimize potable water use in our operations and implement effective stormwater management through water sensitive urban design*

Policy commitment 3

Assist our community in reducing greenhouse gas emissions and build resilience to climate change, including by

a) *Working with the NSW Government to achieve best practice reductions in greenhouse gas emissions, potable water use, and urban heat impacts via our urban planning instruments*
b) *Increasing tree canopy cover and vegetation in streets and reserves*

c) *Providing appropriate public places and systems to create refuges from extreme heat for vulnerable residents.*

Each of the three policy commitments has a list of required actions. Various sections across the Council will be responsible for building resilience and reducing greenhouse gases relevant to their particular field of work. The full policy is accessible in attachment 6.

3.2. Blacktown Integrated Transport Management Plan (ITMP)

The Blacktown Vision 2030 strategic plan identifies the importance of sustainable and integrated transport. This strategic plan responds to the need for a future to cater for transport needs and planned growth in Blacktown City, manage road congestion, reduce reliance on car use, and increase the use of sustainable transport, especially for local trips.

The *Blacktown Integrated Transport Management Plan* (ITMP) is the culmination of several planning studies that incorporated various aspects of transport planning and infrastructure. The ITMP consolidates all the transport elements from those studies into a single document for the first time (Noor, 2013).

Blacktown City will be required to cater to the transport of a predicted 500,000 people and 180,000 dwellings by 2036 (Noor, 2013). Simultaneously, there will be a move towards more sustainable transport modes than car use, such as walking, cycling, and public transport. Action plans have been developed, including target implementation timeframes and responsible authorities have been allocated for specific actions. The key elements of the action plans are as follows:

- Ongoing lobbying to the NSW Government for planned road infrastructure
- Ongoing lobbying to the NSW Government for improved public transport including the North West Rail Link, and implementation of strategic bus corridors
- Adopting proven sustainable transport, land use, and travel demand
- Management practices
- Ongoing lobbying to the NSW Government for regional bike routes and implementation of the *Blacktown Bike Plan*, and improved pedestrian links within the Blacktown central business district (CBD) and town centers

- Implement recommendations from parking review.

The action plan shows that Blacktown is committed to adapt sustainable transport. This study aligns with the Council's plan to introduce a solution for sustainable transportation. The Plan recognizes that local level choices provide a significant opportunity to create a community that has a reduced impact on resources, maintains productivity in the economy, and supports a high quality of life.

Table 6 shows growth in the various types of vehicles in Blacktown LGA. Heavy vehicles have a growth of almost 5% per annum, which displays their contribution in CO2 emission. Therefore, this study will develop carbon emission reduction scenarios to deal with these types of vehicles (Noor, 2013).

Table 6: Growth in the various types of vehicles in Blacktown LGA (Noor, 2013)

Vehicle type	2003	2009	Average annual growth
Passenger vehicles	105,575	120,404	2%
Off-road vehicles	8439	15,825	15%
Light trucks	16,528	20,831	4%
Motorcycles	2907	4599	10%
Heavy vehicles	3495	4505	5%
Total	136,944	166,164	4%

3.2.1. Factors affecting GHG emission in heavy vehicles

Based on my review of the available literature on the causes of GHG emissions in trucks, the major contributors were found, listed below, and in Figure 12 (Clean Air Initiatives (CIA), 2010; EPA, 2012; Rizet, Cruz, & Mbacké, 2012; UNEP, 2009; Wahyudi, Ganis, Soemarno, & Mulyono, 2014)

1. Factor related to truck efficiency
2. Factor related to fuel type
3. Route-related factors
4. Factors related to driving behavior
5. Factors related to retrofitting

After reviewing the literature which is presented in chapter 5 factor number 3- route related factors were chosen for investigation. It excluded truck efficiency, fuel type, and retrofitting, since any changes in the efficiency, fuel type, or retrofitting of the Council's trucks requires a much larger budget, making it difficult or even impossible to implement at this stage. In addition, factors related to driving behavior entailed the installation of specific equipment in the trucks, to monitor and record the driving behavior of a sample driver. It also needed several high-level permissions for installing the monitoring equipment and accessing data, which makes it very difficult to undertake in this research study. As stated in chapter 2, this thesis aims to develop a toolkit for GHG emission reduction and select 3 tools to be examined and quantified in each sector. Any of the proposed mechanisms in chapter 8 could be chosen, but the route-related factors was selected since it was one of the council's priorities and was in the range of my expertise. Additional information on the importance of this specific tool and the associated literature were provided in chapter 4. Instead, the Council kept an extensive log of fuel-related data, which was used in this study. The relevant authorities were interested to the results of route optimization and were ready to implement the new changes. These changes might include installing a new central server, a particular software, and truck-tracking device on each vehicle. Considering the current system for planning the daily missions of trucks was out of order, a simulation model was developed for investigating the proposed route optimization system. If the results of this simulation model show an acceptable level of reduction in fuel usage, the Council will install a trial version of the suggested model. This initiative, its methods, and the results, are presented in GHG emission Reduction in Transportation.

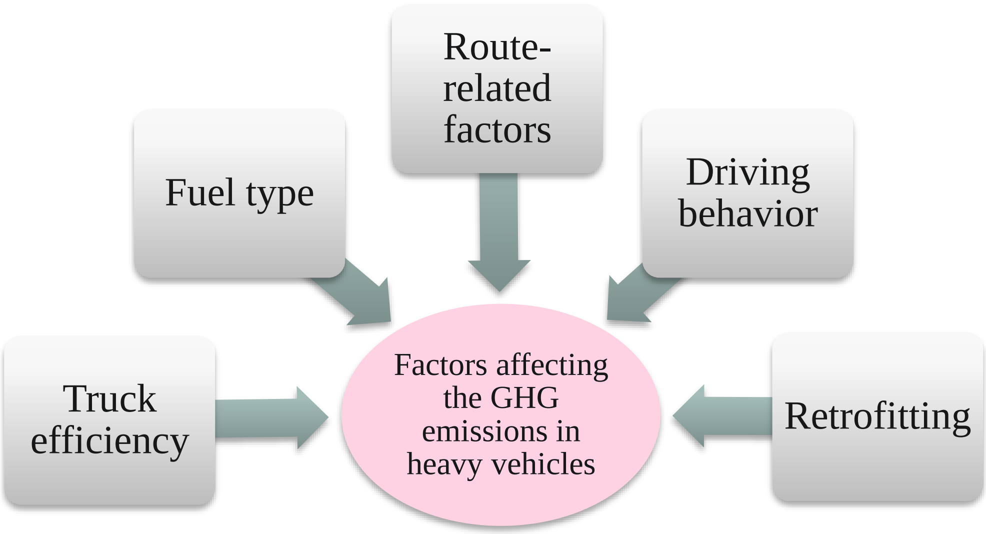


Figure 12: Factors affecting the GHG emissions in heavy vehicles

3.3. Blacktown Waste Reduction Plan in Environmental Sustainability Framework

Blacktown city has a specific framework for Environmental Sustainability. It includes some sub-sections such as Asset, People and Settlements, Water and Catchments, Biodiversity, Climate and Atmosphere. The waste management plans and policies are under the subsection Environmental Sustainability Policy- People and Settlement-

Attachment 4 Blacktown City- Environmental Sustainability **Policy**.

According to this policy, "*Blacktown City is working to rehabilitate waterways, conserve and protect local bushland and wildlife, extend native habitat, improve air quality, and **reduce waste** and carbon emissions to provide a healthy environment for residents of Blacktown now and in the future*."(Blacktown City Council, 2009)

The other part of the policy emphasizes the participatory process of waste management in the city, stating:

"*We are committed to enhancing our environmental awareness and to engaging with our community to improve environmental outcomes throughout Blacktown City. We work in partnership with our community, our suppliers and other stakeholders to continuously advance our journey toward sustainability*."

This journey involves striving to

- *"Protect and enhance biodiversity*
- *Reduce our consumption of resources*
- *Take action to* ***reduce our waste and carbon pollution***
- *Engage with our community to support and encourage improved environmental outcomes."*

It also mentions the Council's approach to reducing its ecological footprint in its day-to-day operations as follows: "*Reduce the consumption of resources,* ***minimize the environmental impacts of waste*** *and improve recovery and diversion rates*."(Blacktown City Council, 2009)

As is obvious from the high-level policy and plans of the Council, there is a sustainable approach to the waste management process with particular focus on minimizing landfill wastes and reducing GHG emissions. Considering these two sustainable strategies of the Council, this research study investigates the possible scenarios for reducing the Council's waste. The methodologies and results of this section are presented in GHG emission Reduction in Waste Management.

3.3.1. Base line of the Waste Stream in Blacktown City Council

Figure 13 (McGregor Environmental Services, 2010) illustrates the general categories of the waste stream in the Council's assets. As this figure shows, the highest proportion of the waste stream is for recyclable waste at 37%, followed by compostable waste at 33%, and landfill waste at 30%. This almost equal proportion of each waste type in the total waste stream confirms significant opportunities for recycling and composting of waste placed in landfill bins by mistake. This is the focus of this research project in terms of waste management, to update the waste stream statistics in the Council's assets, and identify and formulate opportunities to reduce landfills.

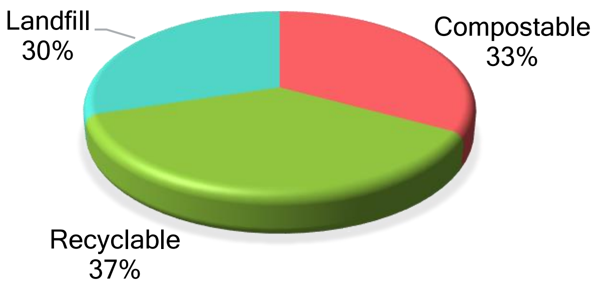


Figure 13: Council's total waste stream

Based on the baseline analysis of different types of waste in Blacktown City Council and a comprehensive literature review presented in chapter 6, it is decided to investigate the possible scenarios for landfill waste reduction at two case studies. These pilot assets were chosen from various categories— a library and a swimming pool— to represent these two types of assets in the project.

The objective would be measuring the waste stream in these two centers, investigating the possible scenarios to reduce landfill waste, and calculating the GHG emission reduction in the proposed scenarios. The associated methodologies and results in the section, will be presented in GHG emission Reduction in Waste Management chapter.

3.4. Blacktown Urban Forest Policy and Guidelines

Blacktown City has a clear policy for urban forest and trees. The Council has developed this document to set the policy direction and provide guidelines for the planting and maintenance of trees. This policy also incorporates the particular short-and long-term plans for planting and maintenance of street trees, which is the focus of this study. The whole policy is presented in

Attachment 5 Blacktown City- Urban Forest Policy & Guidelines. However, the highlighted parts relevant to the planting and maintenance of street trees are as follows.

Objective 1 of this policy states:

"*Improve the health, and increase the extent, of the tree canopy cover to provide environmental and social benefits to the City*"(Blacktown City Council, 2016b).

Under this objective, the action is to

"Develop long term strategies to increase the quantity and quality of Council's tree population in both the streets and parks" (Blacktown City Council, 2016b).

This research study considers this objective as a high-level governmental document to investigate the impacts of street tree planting on Urban Heat Island mitigation.

3.4.1. Baseline of the Council's tree planting projects

To conserve its biodiversity, combat land use change, and reduce Urban Heat Islands (UHI), the Council undertakes several bush regeneration projects funded through grant programs, Council's Works Improvement Program, and maintenance budgets. Figure 14, shows the number of trees and shrubs planted by the Councils and volunteers under Council programs to reduce GHG emissions and combat urban heat island effects (Blacktown City Council, 2011).

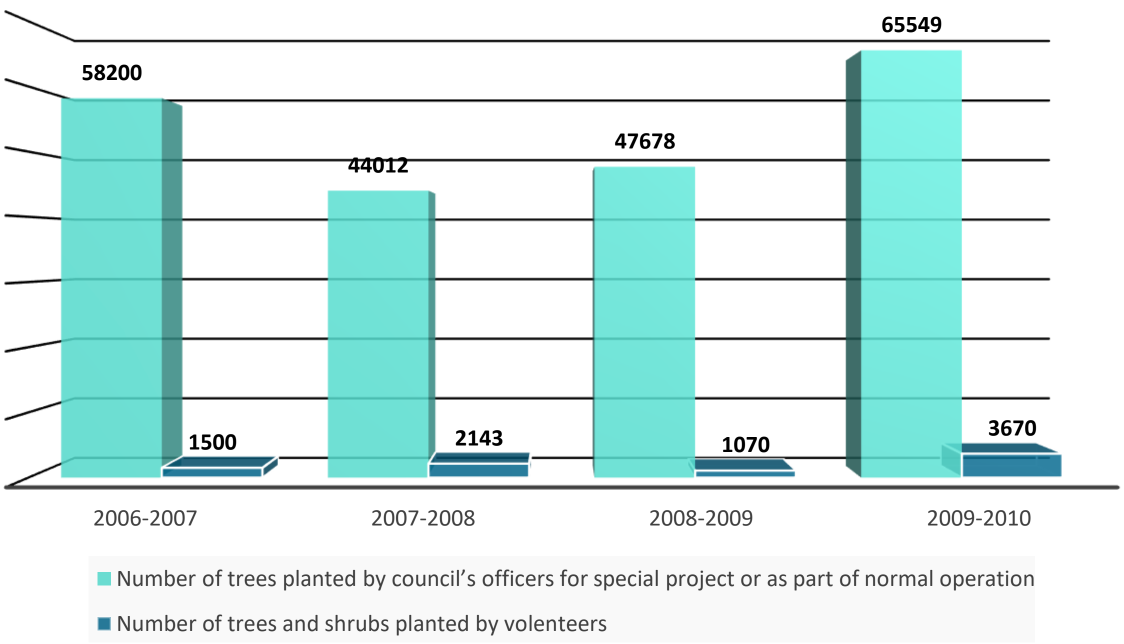


Figure 14: Number of trees and shrubs planted by Council and volunteers groups

While the Council undertook considerable carbon forest planting through its Regenesis project, there may be additional opportunities for sequestration in trees. There are also opportunities for street tree planting and the other cooling street scenarios to reduce the urban heat island effect. This research investigated the effects of the street planting project and other possible strategies in carbon sequestration and reducing the Urban Heat Island effects.

The main aim in this section is to determine the strategies to reduce the UHI effect in the selected Case study of the city. This goal will be achieved through a group of secondary aims, as follows (Calderón-Contreras & Quiroz-Rosas, 2017; Connop et al., 2016; Estoque, Murayama, & Myint, 2017; Hsieh & Huang, 2016; Jayasooriya, Ng, Muthukumaran, & Perera, 2017; Kubota et al., 2017; Lehmann, 2014; W. Li, Cao, Lang, & Wu, 2017; O'Malley, Piroozfarb, Farr, & Gates, 2014; Rehan, 2016; Salvati, Coch Roura, & Cecere, 2017; Santamouris, 2014; X. Xu et al., 2017):

- Develop a visual image of cities by highlighting the importance of urban parks and green open spaces.
- Increase resilience to global warming by establishing green corridors through urban design.
- Improve air quality and ventilation in cities by applying green infrastructure principles.
- Create an attractive urban environment and reduce the temperature of cities by using water in the urban landscape.
- Generate applicable measures for urban designers to improve the urban microclimate, focusing on heat.

The associated methodologies and results of this section will be presented in the GHG Emission Reduction by Managing the chapter.

3.5. Council's Current Carbon Accounting in the Scope 2, 3

Since 2005, the Council has engaged Planet Footprint to use the electricity, gas bills, and fuel use data to calculate carbon emissions. This gives the Council robust information on the levels of greenhouse gases emitted as a direct result of the Council's energy use. However, it does not cover emissions from goods and services that the Council procures, which are unrelated to fuel, electricity, and gas.

Carbon accounting is an internationally and nationally recognized system of calculating greenhouse gas emissions.

Carbon accounts are divided into three scopes to prevent double counting across the economy

- Scope 1 includes emissions from fuel that we burn directly, for example, mains gas and vehicle fuels.
- Scope 2 includes our grid-sourced electricity and street lighting.
- Scope 3 includes emissions related to the delivery of our energy and fuels. The main examples are emissions from transmission loss along the power lines to us, and from the fuel transport trucks delivering our fuel.

In 2016/17, the Council's emissions from street lighting and operational electricity, fuels and mains gas totaled 36,642 tons of carbon dioxide equivalent (t/CO2e). This includes the supply chain emissions from delivering energy, such as generating electricity that was lost during transmission, and emissions from the fuel used by tankers to deliver the Council's fuels. If the Council does not make changes, these greenhouse gas emissions will increase with its growth.

As shown Figure 15, of the 36,642 t/CO2e, just over 80% relate to electricity (including street lighting), almost 14% relate to fuel and nearly 6% is from mains gas.

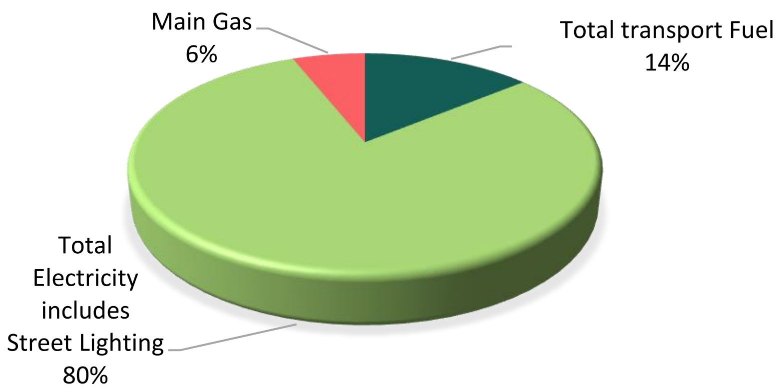


Figure 15: Council's 2016/17 known greenhouse gas emissions from electricity, fuels, and mains gas

As this figure shows, there is an obvious opportunity to reduce the Council's GHG emission by lowering the electricity use, which also includes street lighting. Investigating strategies to reduce GHG emissions in the electricity sector is beyond the scope of this research. However, since the topic of this research study is designing a toolkit to reduce the GHG emission, I undertook a comprehensive review on the Council's actions thus far to mitigate the energy consumption of its assets. I also compared all measures that the Council has undertaken to reduce energy consumption and propose the best and most cost-effective solution to reduce GHG emission in the electricity sector. The results of this section are in the GHG emission Reduction by .

This chapter introduced the case study of the research and also the main source of data. Firstly, in section 1 in this chapter, Australia's action against climate change was explained, and Blacktown City Council was introduced. In this chapter, Blacktown City environmental plans and policies were presented, including Blacktown responding to climate change policy, Blacktown integrated management plan, Blacktown waste reduction plan, and the Council's current carbon accounting in the three scopes. A general overview of the materials and methods of this study is presented in chapter 4.

CHAPTER 4

Materials & Methodologies

SUMMARY

This chapter introduces the applied methodologies in the study. Firstly, it explains the necessity of a GHG emission reduction toolkit in an urban scale, then the procedure of structuring the kit and its main elements are introduced. Finally, a snapshot on the applied methods for piloting the tools are presented and their linkage is presented using a road map of applied methodologies.

1. Introduction

Rising global temperature leads to rising sea levels, changing precipitation patterns, increasing extreme weather, and dissemination of tropical diseases. All of these affect the urban area's fundamental services, infrastructure, land use, human life, and health. By 2070, summer in Sydney, New South Wales may be almost 4 degrees warmer and 73 percent wetter. Winter in Melbourne may be more than 4 degrees warmer and nearly 25 percent drier. These are the trends in just two of the Australian cities. The notion is to convert global forecasts into something less distance, less objective, more geographically local and to the point. Since cities account for almost 75% of the worldwide climate change, translating global patterns into tangible insights is of particular significance (UNEP, 2018).

Cities aren't just where the impacts of climate change may occur, but also where the solution can be drawn up. Many municipal leaders are already experimenting with initiatives to reduce emissions, but the challenge is understanding where to focus. Success can be reached just through global, national, and local levels of inter-sectoral collaborations. It is crucial, though, to consider urban areas an integral part of combating climate change strategies. Many cities are already doing a lot with sustainable policymaking, regulations and incentives, renewable energies, and efficient, low-energy-consume technologies.

This chapter deals with the urban scale solutions on combating climate change, by introducing the GHG emission reduction toolkit and the methodologies by which such a kit was extracted. The key concepts of a GHG emission reduction toolkit are introduced in this chapter. Since piloting three suggested tools from the toolkit is one of the critical areas of this research, the generic methodologies applied for the case studies also presented in this chapter. In the end, a roadmap illustrating the linkage between the used methods is presented.

2. Identifying the Relevant Literature

For developing a GHG emission handful of solutions, a comprehensive review of the literature was undertaken by the author. The period of study was between the years 2000 and 2020 to cover the most recent literature. The research key for the review was "GHG Emission Reduction Toolkit," with this term, all the relevant resources in any parts of the article emerged. The number of results was 1380 out of them 122 were quite pertinent, and 25 were precisely to-the-point. The collections where the literature review was taken from, and the journal names are illustrated in Table 7.

Table 7: The list of collections in which the GHG emission reduction toolkit were extracted

Collection	*Number of results*
ProQuest Central (new)	307
SciTech Premium Collection	294
Science Citation Index Expanded (Web of Science)	156
Social Science Premium Collection	92
Social Sciences Citation Index (Web of Science)	84
Directory of Open Access Journals (DOAJ)	75
Springer (CrossRef)	65
SpringerLink	51
Taylor & Francis Online - Journals	44
Informa - Taylor & Francis (CrossRef)	38
ScienceDirect (Elsevier)	31
Elsevier (CrossRef)	31
MEDLINE/PubMed (NLM)	28
SpringerLink Open Access	17
JSTOR Sustainability	15
Emerald Insight	12
Sage Journals (Sage Publications)	12
Oxford University Press (CrossRef)	10
ProQuest Entrepreneurship	10
JSTOR Archival Journals	8

As this table shows, most of the resources were from the ProQuest Central, followed by the SciTech Premium Collection, Science Citation Index Expanded (Web of Science) with 307, 294, and 156 respectively.

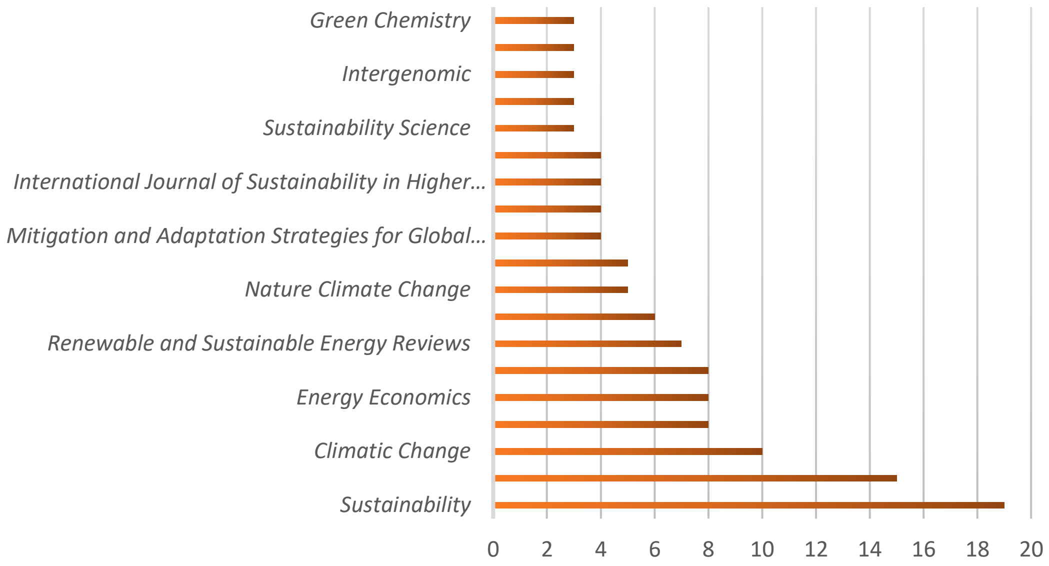


Figure 16: The list of journals in which the GHG emission reduction toolkit was extracted

Also, the list of journals in which the GHG emission reduction toolkit was extracted is shown in Figure 16. This figure shows most of the toolkit's references cited in the Sustainability Journal followed by Energy and Climate Change with the number of articles 19, 15, and 10, respectively. It should be mentioned that the classification of the toolkit's episodes was based on the thematic analysis of the literature. All the relevant resources were firstly gathered and then classified into some equivalent classes, as represented in Figure 17. Also, the main sources of data, final selected articles with their technical details presented in Table 23 of chapter 9.

3. Structuring the GHG Emission Reduction Toolkit

The literature review for the development of the GHG emission reduction toolkit was a concept-centric process. It means that the concepts determined the organizing framework of the review in addition to the requirement for developing such a toolkit. The idea was to consider the concepts as a centric point in the kit's thematic frame and its component? For instance, Practice Greenhealth (2018), developed a GHG emission reduction toolkit, with the main focus on protecting health. In their strategic document, it is stated that Climate change is the most significant public health threat and opportunity of the 21st (Practice Greenhealth, 2018). To mitigate the health impacts of greenhouse gas emissions, hospitals have a critical role to play. In line with this strategic approach, they set 4 main headlines for the toolkit, including ROI and Risk Management, Fiduciary Responsibility, Enhanced Reputation, and coverage Stability. Council for Sustainable Development (2011), as another example, put its central focus on energy saving. The toolkit was formed and classified on an energy-saving basis, and thus, its main highlights are systemic enhancement and facilitating behavior change. There are some sub-titles under each category, such as tightening the building energy code, high energy efficiency, mandatory energy efficiency labeling scheme, promoting the adoption of energy-efficient electrical appliances among the trades, and electricity tariff structure review.

Also, the scale on which a GHG emission reduction toolkit is developed varies from micro to medium and to macro. Association of Bay Area Government (2018a), developed a medium-scale toolkit for local and regional government. This is a type of policymaking instrument for the city planners to respond to climate change. Therefore, the toolkit investigates the engagement process, identification of hazards and assets, developing strategy, and evaluation. Camco Advisory Services Ltd. (2014), as another example, developed a macroscale toolkit on Resources and Opportunities (CaRROT) in Kenya for the flowering industry. This toolkit targets the transition of the flower sector to a low carbon emissions section. It also promotes appropriate mitigation measures and strengthens the resilience of the area against climate change impacts through practical adaptation solutions targeting energy and water use.

The other significant factor, for structuring a toolkit, is the emission-associated elements such as abatement potential and the scopes in which the emission is reduced. Estimating the abatement potential of a suggested initiative can be the hardest part of developing a toolkit. Not all of the techniques are capable of quantification, and if even so, it could be a time-consuming process. In dealing with this problem the author, reviewed the related literature mentioned in section 2 of this chapter and section 5 of chapter 9. As stated in Table 23, the multiple sources were used to estimate the mitigation capacity of the offered technologies. The abatement potential was categorized in three levels from high to medium to low accordingly.

The column 5 of the toolkit, represents the scope in which the GHG emission will be deducted. The logic behind choosing the scopes bases on the scopes' definition. Scope 1, associates with a reduction from direct emissions from owned or controlled sources. Scope 2, relates to emissions reduction from indirect emissions from the generation of purchased energy, and scope 3, are those techniques mitigate GHG from indirect emissions (not included in scope 2) that occur in the value chain of the reporting company, including both upstream and downstream emissions (World Resources Institute, 2017).

Figure 16 illustrates fifteen headlines extracted from a comprehensive literature review on chapter two and this chapter across four action areas that will affirm cities' roles as climate change leaders and help stall the rise of global temperatures within the 'safe' limits.

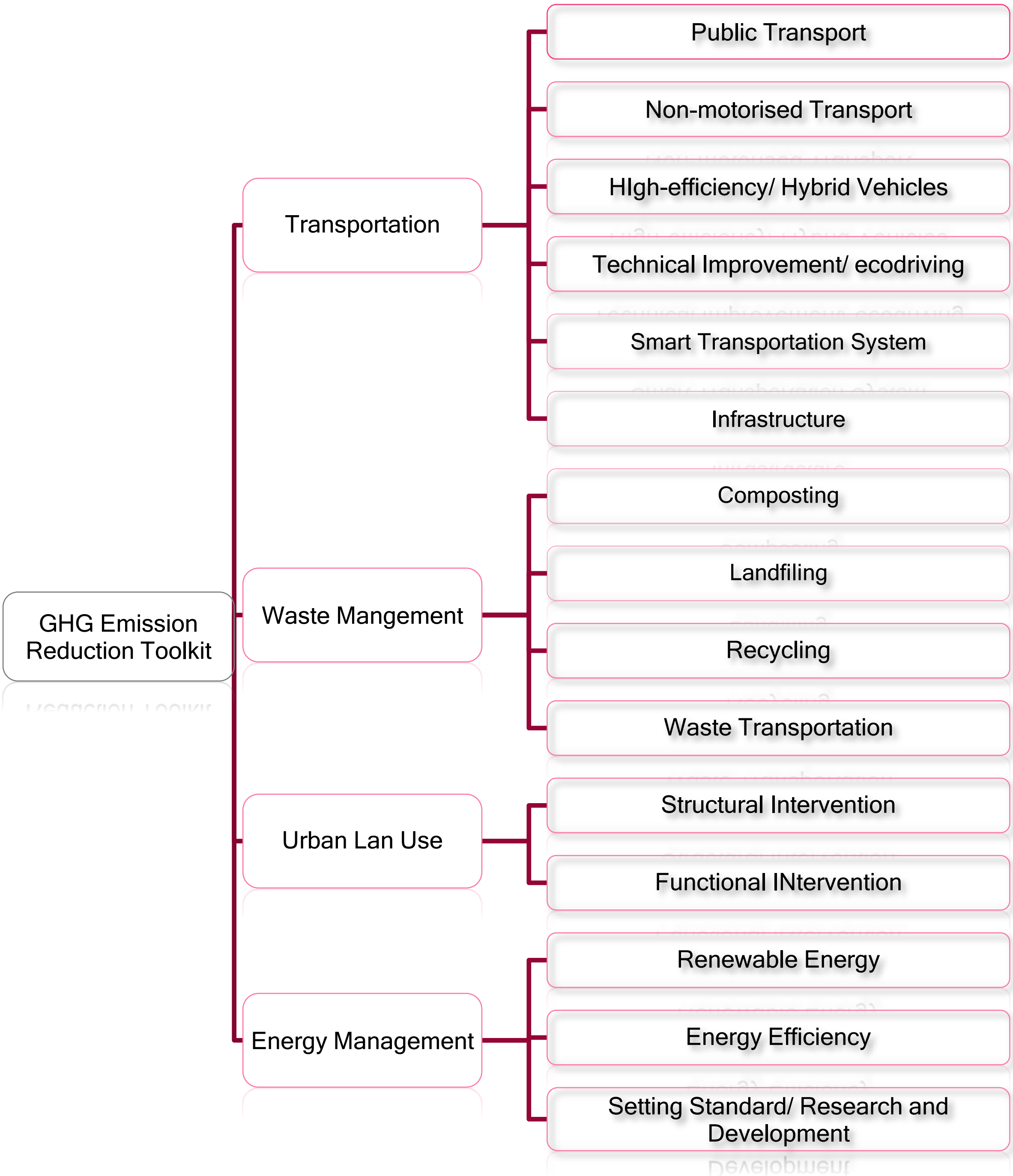


Figure 17: The structure of the GHG Emission Reduction Toolkit

4. Quantifying the Toolkit

One of the main objectives of this research study was to quantify the 3 sample tools from the toolkit and examine it for the Blacktown City Council. Piloting such a toolkit and measuring the potential of GHG emission reduction demonstrate the applicability of such a kit on the ground. This provides city planners with the amount of GHG emission reduction and prioritizes their budgeting and resource funding programs.

There is always an ambiguity about the outcome of our GHG abatement plans on the ground? To what extend the reduction techniques are effective? And does it worth to fund mitigation projects? Are they applicable and are accepted by the communities? These and many same questions are parts of constituting this section of the thesis. To quantify three selected case studies from each sector and pilot it for the Blacktown City Council.

GHG reduction tools enable city planners to develop comprehensive and reliable inventories of their GHG emissions, and help states and towns follow progress toward their climate goals. Calculating emissions and emission reduction is a multi-step process. A precise and helpful inventory is constructed after careful consideration of quality control problems. Only then should emissions and the associated mitigation potential be estimated

Measuring contribution to mitigating the global GHG emission caters stimulant to success. Therefore, the visualization of contribution to mitigating greenhouse gas emission is crucial. For instance, as one attempt toward this objective, Japanese industries used a system called "pledge and review." This system required companies to pledge their contribution to GHG emission reduction and their target, implementing initiatives to achieve their abatement targets, and monitor and evaluate them. Also, some industries in Japan step forward to measure their GHG emission reduction which is called "Avoided Emissions" (Pajon, 2010). Also, developed consumption-based life cycle accounting techniques to measure the GHG emission of typical US household. Their model quantified emissions embodied in transportation, energy, water, waste, food, goods, and services and further investigated the associated mitigation actions in all household types.

This part of the study introduces the methods used in this study to quantify the 3 selected GHG emission mitigation tools from the developed toolkit.

Table 8: The Summary of the methodologies applied in this study for the toolkit's quantification

Sector	Sub-sector	Technique	Methodologies
Transportation	Smart Navigation System	Route Optimization	Formulation of the Routing Problem Using Network Analyst in GIS
			Formulation of Fuel Consumption Rate for Heavy Truck
			Calculation of GHG Emissions for On-road Heavy Vehicles
Waste Management	Landfilling	General waste reduction	Evaluating Baseline of the Waste Stream in the Council's Assets
			Impact Assessment of the Disposal of Municipal Solid Waste
			Calculation of Greenhouse-Gas Emissions from Landfilling
			Calculation of Greenhouse-Gas Emissions from Electricity Consumption
			Calculation of Greenhouse-Gas Emissions from Waste Transportation
			Development of a Waste Management Plan for the SPECIFIED Public Facilities
Urban Land use	Urban Structure	Mitigating Urban Heat Islands	Urban Texture Analysis using EnviMet Model
			Making Cooling Street Scenarios and Scenario Analysis
			Validation of the Model
			Assessing Parameters
Energy Management	Energy Efficiency	Analyze the Council's green initiatives	Selecting Energy Audit Process: - ASHRAE Level II, III - IPMVP Options A, B, C
			GHG Emission Calculations from the Council's Green Initiatives
			Compare the Council's Initiatives
			Cost-Benefit Analysis

As Table 8 shows, the quantifying of the toolkit is divided into four groups. For transportation, the Route Optimization tool from the Smart Navigation System was selected. For optimizing the route, the Network Analyst Model in GIS was chosen as the optimization model. The truck's origins and destinations were added to the model, and the best route considering all the limitations was selected. The total distance-traveled were compared in an optimized way versus the regular way in the next stage, and the associated reduction in the GHG emission was calculated.

For Waste Management, General Waste Reduction was selected in the Landfilling sub-sector. The baseline of the waste stream firstly estimated in the two selected case studies and some reduction scenarios were proposed for mitigating the general waste in their source points including Removing organic food from the waste stream, Removing paper towels from the waste stream, Removing coffee cups from the waste stream and Removing Plastic Bags from Waste Stream. In the end, the amount of GHG emission reduction from each scenario was calculated and compared with the baseline as-usual scenario. In the end, a waste management plan was developed for the Council.

For Urban Land Use, Mitigating Urban Heat Islands was selected from the Urban Structure sub-section. Firstly, the urban texture was analyzed using Envi-Met software, and some cooling street strategies were proposed to analyze their effect on temperature reduction. Then the validity of the model was examined using NSW weather data, and finally, the model was calibrated. Green Canopy and Cool Pavement scenarios, specifically, were analyzed using the Envi-Met model, and their potentials for temperature reduction was calculated. In the end, the other parameters were assessed, and the final cooling street strategies were proposed.

For Energy Management, the Council's green initiatives were analyzed in the Energy Efficiency sub-section. For this purpose, a comprehensive list of the Council's green initiatives was gathered and compared. Payback time, cost per tonne of reduction, and the potential decrease of GHG emission were the assessed parameters. In the end, the most and the least cost-effective initiatives were introduced.

5. Summary

Figure 18 illustrates the road map of developing the research idea and methodologies. As this figure shows, the IPCC agreement triggered the research idea on keeping global warming at a 1.5°C level. Following this agreement, all the member countries committed to submit their plans to reach this goal by 2030. Australia's commitment to mitigate its GHG emission by 26-28% below 2005 made the main framework of this study to develop a GHG emission reduction toolkit for the Australian Cities. The details of the methodologies are presented in the associated chapters.

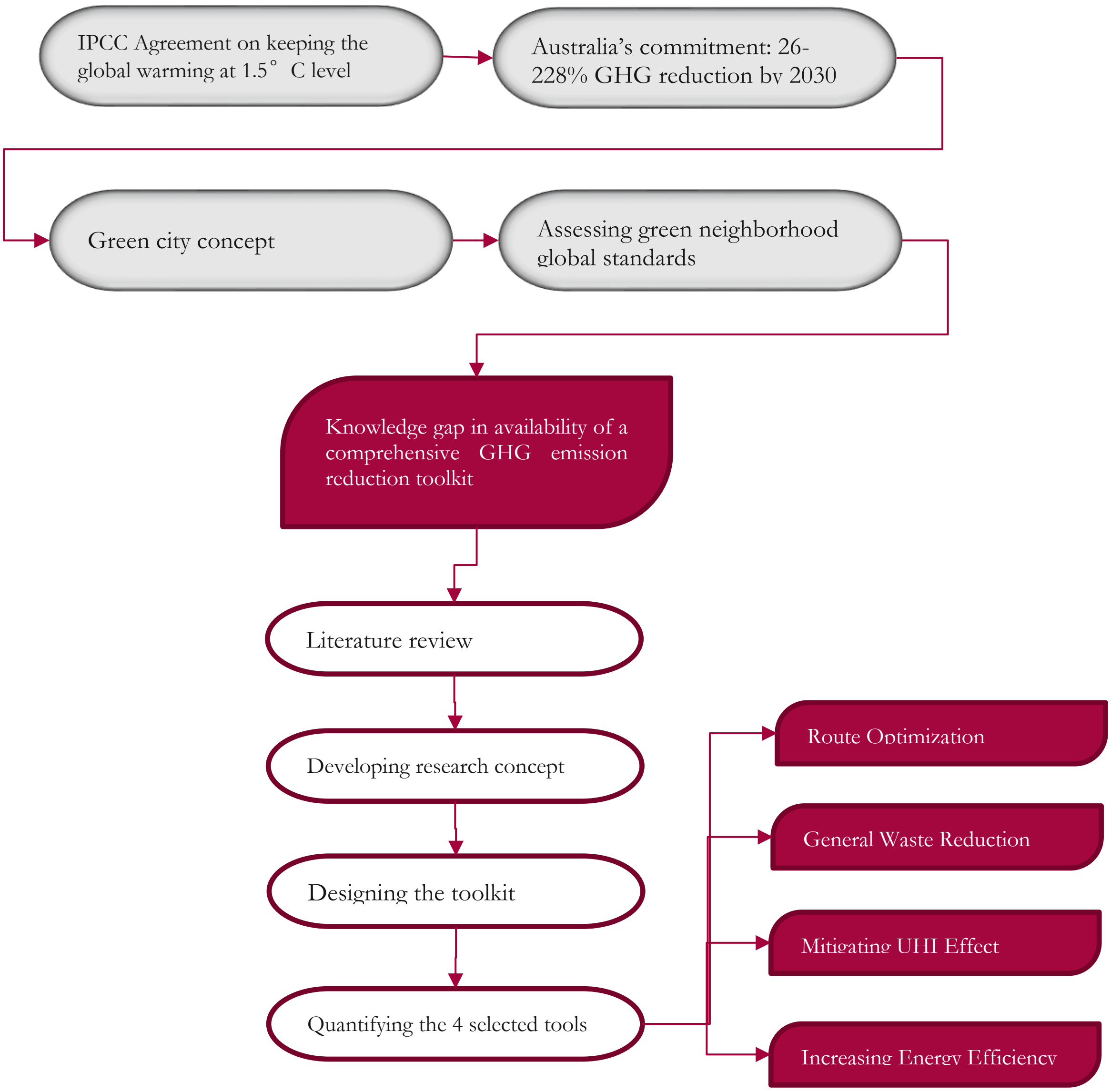


Figure 18: The road map of developing the research concept and methodologies

CHAPTER 5

GHG emission Reduction in Transportation

SUMMARY

This chapter evaluates the impact of route optimization of heavy vehicles on fuel consumption and GHG emissions. The regular travel distances of two piloted trucks of Blacktown City Council are measured and compared with the optimized lengths suggested by the optimization model.

The results of this chapter feed toolkit's chapter in terms of abatement potential of some introduced tools.

1. Introduction

Transportation, which is moving people or commodities from one point to another, has three main sectors: 1- infrastructure, 2- equipment, and 3- function. From a different perspective, it can be categorized in three main modes: road, maritime, and air transportation. Road transport is a significant part of any economy and accounts for a considerable portion of the GDP in almost every country. It also plays an important role in the supply chain of nearly all goods and industries. From the beginning of the 20th century, this industry has played an important role in the balanced distribution of wealth around the world. By shifting goods and infrastructures between places, it has added flexibility to other industries as well. However, this sector is responsible for a significant portion of global emissions (Pulles & Yang, 2011). Road transport accounts for 17.5 % of overall greenhouse gas emissions in Europe and 15.5% in Australia (Bureau of Infrastructure, 2009; European Environmental Agency, 2012). Besides its advantage of easing world trade and increasing flexibility, road transportation causes 73% of GHG emission among all other modes of transport (International Transport Forum, 2010; Klungboonkrong, Jaensirisak, & Satiennam, 2015). With predictions of rising demands for road freight transport, traditional modes of moving people and goods will require more resource-efficient transport systems. The key goal is to reduce fuel consumption and thereby GHG emissions (Birol, 2010; Karimipour et al., 2015; Zeng, Miwa, & Morikawa, 2016).

2. Previous Studies

Several solutions have been suggested to reduce the fuel consumption of road freight transportation. They range from equipment improvement, such as changing the fuel type and shifting to hybrid/ electric engines to behavioral change, such as changing driving behavior and using public transport (Mills & MacGill, 2017). The recent developments in improving the efficiency of road freight transportation insists on an Intelligent Transportation System (ITS) (Cohen-Blankshtain & Rotem-Mindali, 2013). The ITS is a set of software, knowledge, and hardware implemented in a transportation system to improve its efficiency. One popular tool of the ITS is efficient vehicle routing and scheduling.

Efficient vehicle routing and scheduling can be formulated as either an efficient routing system or scheduling scheme. Efficient vehicle routing supposes that a vehicle or a fleet of vehicles have to visit several points and minimize certain costs (Bandeira et al., 2014). This cost can be fuel consumption, GHG emissions, distance traveled, or any other charge. Efficient vehicle scheduling supposes that a vehicle or a fleet of vehicles have to accomplish a certain mission, which should minimize the total cost of traveling. For example, this can be a fleet of on-road heavy vehicles, which are on-call, and must visit certain nodes per day. In this situation, instead of defining a fixed route for each vehicle, the fleet path can be defined as the sum of the minimum distance to the nearest points, so that the total distance travelled by whole fleet can be minimized (Longo, de Aragão, & Uchoa, 2006; Zsigraiova, Semiao, & Beijoco, 2013).

Whatever the techniques used for efficient vehicle routing and scheduling problems; heavy vehicle systems are strongly of spatial nature. Therefore, it is possible, and advisable, to take advantage of an analytical software such as Geographical Information System (GIS) and Remote Sensing (RS), which are demonstrated to be potent tools that provide detailed spatial information and its effective handling (Tarantilis & Kiranoudis, 2002).

Several studies, especially in recent years, have focused on efficient vehicle routing for reducing GHG emission. Zeng et al. (2016) worked on the application of eco-routing navigation on greenhouse gas emission. They developed a model to find the optimal path using weighting method and k-shortest path algorithm. E. Yao and Song (2013) also introduced an eco-routing model combining standard shortest-path algorithm and a dynamic database for traffic information database. Masikos, Demestichas, Adamopoulou, and Theologou (2015) developed an energy-efficient routing model utilizing the vehicular consumption predictions of a mesoscopic learning model.

The heavy truck transportation model and its application to fuel efficiency has also received scholarly attention in recent years (Soleimani, Chaharlang, & Ghaderi, 2018). Hosseini-Nasab and Lotfalian (2017) developed a model based on path type to find a green route for trucking systems. Mourão, Nunes, and Prins (2009) proposed two-phase heuristics and one best insertion method for solving a sectoring arc routing problem (SARC) in a municipal waste collection problem. In their model, the street network is partitioned into several sectors, and a set of vehicle trips is built in each sector that aims to minimize the total duration of the trips.

Considering the importance of reducing GHG emissions in the transportation sector and from the perspective of previous studies, this study takes a new step in quantifying the fuel usage and GHG emissions in heavy vehicles using efficient vehicle routing. The main aim is to quantify the distance driven by the different types of heavy vehicles in the optimized routes compared with their regular routes. The methodology is a novel approach of its kind, in terms of implementing the optimization model on two different types of heavy vehicles with different missions. It aims to find ways to reduce the overall travel distance for different types of heavy vehicles to reduce fuel consumption, and therefore, GHG emissions.

Hence, the main objectives of this research study are investigating the effects of route optimization in the daily routes of heavy vehicles on:

- Reducing fuel consumption
- Reducing GHG emission from the consumption of fossil fuel

In line with Australia's policy to reduce GHG emissions by 26-28% below the 2005 level by 2030, (Australian Government, 2016), Blacktown is working on mitigating its CO2e emission. This study investigates opportunities for alleviating GHG emission through route optimization in Blacktown City Council.

For this study, we select two trucks of the Blacktown City Council to investigate the applicability of a route optimization model for improving fleet fuel efficiency. These two trucks are from the waste collector and tree maintenance teams. The regular travel distances of these trucks were extracted and compared with the optimized distances simulated by the optimization model.

3. Materials and Methodology

3.1. Formulation of the Routing Problem

Finding the shortest path in a web of streets and highways is a challenge (Figure 19). To reach a target point in a network, it is necessary to investigate all possible scenarios, which includes every path passing through different junctions but with the same origin and the same destination. Simulating such a model could be complex, as there might be hundreds of junctions between two nodes in a network and the lines (streets). For solving this problem, this study introduces Dijkstra's algorithm. This algorithm finds the shortest path from a starting node to a target node in a weighted graph. The algorithm creates a tree of shortest paths from the starting vertex, the source, to all other points in the graph. Dijkstra's algorithm finds the shortest path tree from a single source node, by building a set of nodes that have minimum distance from the source (Abey, Peng, & Khim, 2017; Baeza, Ihle, & Ortiz, 2017; Mehlhorn & Sanders, 2008).

Nowadays, however, computer software can simulate all possible travel routes between two nodes and find the shortest path. The Arc GIS Network Analyst, used in this study, is one such software, which allows users to optimize routes. This software also is able to generate turn-by-turn directions, route multiple vehicles to multiple destinations, introduce a new point or route obstacle, such as new red lights or speed limitations, and increase the overall efficiency of daily workflows. The program develops efficient vehicle routing by minimizing the overall operating cost/time for the fleet of vehicles (ESRI, 2017).

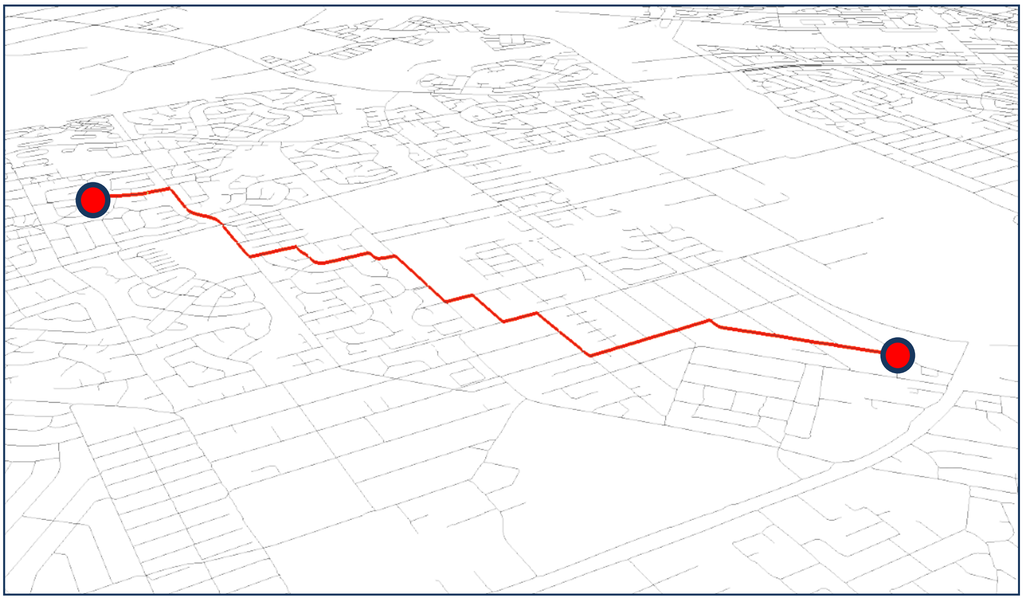


Figure 19: Example of an optimized route between two nodes in a city

To calculate the optimal routes of two trucks, there were several inputs to the ArcGIS Network Analyst solver. 1- An origin point where the truck starts the trip, 2- the collection point where the truck collects garbage or does a specific task and 3- a returning point, which is the final destination (V. W. Y. Tam, Karimipour, Le, & Wang, 2018). These inputs were fed into the Network Analyst at the first stage. In the next step, the error points were cleaned from the source maps. This means that all the gaps in the street layer were filled and the street junctions were also added to the map. In the next step, lines were physically split wherever they intersect, and the network dataset was built with the End Point option. A drive time field was then added to the street layer. Note that ArcGIS automatically adds and uses a length-based cost attribute if no other attribute is specified; however, this base attribute may ignore the fact that some roads, such as freeways, are faster than other roads. Furthermore, different layers for calculating greenhouse-gas emissions have been added to the model, including CO2, N2O, and CH4 emissions for traveling each section of the street. Figure 20 depicts the process of preparing the data and formulating the routing problem in this study.

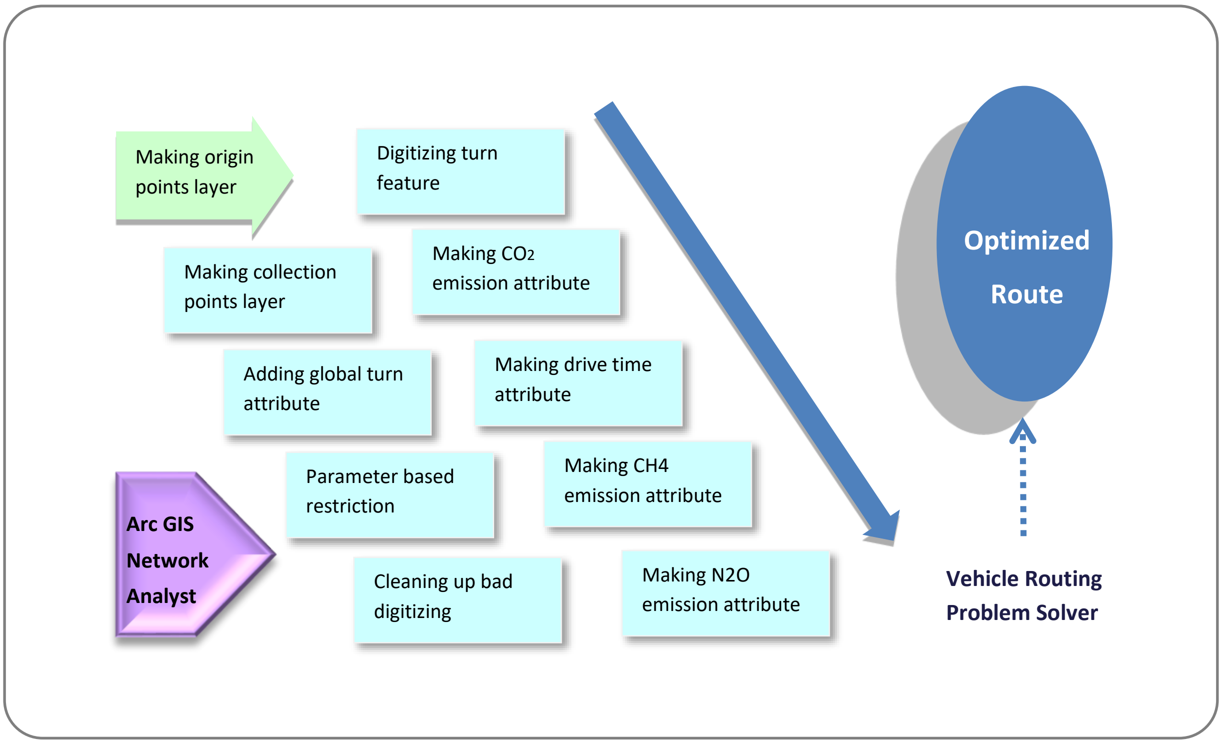


Figure 20: Major project components and system design

3.2. Formulation of Fuel Consumption Rate

The type of truck is an important factor in determining the fuel consumption rate (FCR) (Zhou, Roorda, MacLean, & Luk, 2017). The FCR can be generalized for all types of trucks; however, for the purpose of accuracy and when calculating the GHG emissions from fuel combustion, the precise rate of fuel consumption is important. For instance, the fuel consumption rate for a heavy truck with a set of continuous stop and go missions (e.g., waste truck) and gradually is weighted by waste at each point, would be much different from a heavy lifting truck that has a one empty load- on its way to the destination- and one full load returning. This is why this study selects two types of trucks: to compare their fuel consumption rates and their route optimization results.

The FCR for tree maintenance truck has been estimated according to statistical data of the Council. Since the city Council maintains a fuel log of its vehicles from when they are added to its fleet, calculating the average consumption of each truck per kilometer is not very difficult. However, the FCR for waste collectors is a little different. Waste collection trucks consume fuel during three main activities: (1) traveling outside collection areas; (2) idling in front of each household while waste is loaded; and (3) traveling within an assigned collection area. The fuel consumption rate is different during each phase. Waste collectors act such as other heavy vehicles between the depot and the collection area, and from the end of the collection region to the landfill, distribution center, or drop-off center. However, while collecting garbage bins and emptying them, waste collectors often move at very low speeds due to the stop-and-go nature of the loading process. Therefore, it is necessary to calculate the FCR of each of three stages mentioned above to evaluate the fuel consumption rate of a waste collector. For this study, these three rates were commuting; idling, and house-to-house traveling.

Table 9: Annual fuel consumption estimated for the MSW collection vehicle (Nguyen & Wilson, 2010)

Activity	Idling	Commuting
Proportion of Fuel Consumed	52%	48%
Average rate of fuel consumption	16%	84%

The house-to-house-traveling rate was evaluated based on fuel record logs according to Equation 2.

$$H_t = \frac{F_t - T_1 \times r_1 - (D_T - D_H - T_{rl}) \times r_{Trl}}{D_H - T_{rl}}$$

Equation 2 house-to-house-traveling Fuel Consumption rate (Nguyen & Wilson, 2010)

Where

- *H_t is house-to-house-traveling fuel consumption rate (L km^{-1});*
- *F_T is total daily fuel quantity (L);*
- *T_1 is total idling time (hr);*
- *r_1 is idling fuel consumption rate (L hr^{-1});*
- *D_T is total traveling distance (km);*
- *D_H-T_{rl} is distance traveling within collection areas (km);*
- *r_{Trl} is transportation-traveling fuel consumption rate (L km^{-1}).*

The Blacktown City Council maintains an electronic database of the fueling log for each truck. Normally, waste collectors and tree maintenance trucks fuel once a day and once a week, respectively. With data on kilometers per day and fueling record from the Council database, this study could calculate the fuel consumption rate.

3.3. Calculation of GHG Emissions for On-road Heavy Vehicles

This study investigates the amount of GHG emitted directly from on-road heavy vehicles. These emissions are from vehicle fuel combustion, not from the full lifecycle greenhouse gas emissions associated with trucking activities.

The greenhouse gases, CO2, CH4, and N2O are emitted during the combustion of fuels in mobile sources (Guzman, de la Hoz, & Monzón, 2015; U.S. Environmental Protection Agency, 2016). The amount of greenhouse gas emission on combustion of fossil fuel in vehicles depends on many variables, such as the type, engine, and weight, on the one hand, and driving behavior, distance travelled or quality of the asphalt road on the other (Butt, Birgisson, & Kringos, 2016; Ozcan-Deniz & Zhu, 2015). Therefore, some types of transportation are more efficient than are others; however, whatever the type of transportation, the formula for calculating GHG emission is the same.

Equation 3 has been used to estimate greenhouse gas emissions from the combustion of each type of fuel used for transportation in this study.

$$Eij = \frac{Qi \times ECi \times EFijoxec}{1000}$$

Equation 3 GHG emission formula for heavy trucks (Australian Government, 2015)

Where:

- *Eij is the emissions of gas type (j), carbon dioxide, methane or nitrous oxide, from fuel type (i) (CO2e tons);*
- *Qi is the quantity of fuel type (i) (kiloliters or gigajoules) combusted for transport energy purposes;*
- *ECi is the energy content factor of fuel type (i) (gigajoules per kiloliter or per cubic meter),*
- *EFij is the emission factor for each gas type (j).*

3.4. Limitations of the Study

Although there are many benefits of optimizing the heavy-vehicles routes and shortening the distances, some cones on this approach should be considered. For instance, not all the software's suggested routes can be traveled by heavy vehicles. The general traffic lanes are 3.3-3.5 meters for roads with higher speeds and truck volumes, or 3.0-3.3 meters for lower speed roads with low truck volumes in Australia (Driver Knowledge Tests, 2020). There are some other limitations of using the method too. The on-road traffic at certain times of the day is one of them. Although this model calculates the shortest route, it doesn't consider some of the route factors such as on-road traffic and the number of red-lights in the path. Having some red-lights on the street, the driver may choose a different way from the one suggested by the model. The other limitation is not considering the schools, business centers, and the local hubs. Passing these paths in the crowded time of the day may be strict for a driver since this task requires too many stops and run intervals on the lane, making it hard in the press times.

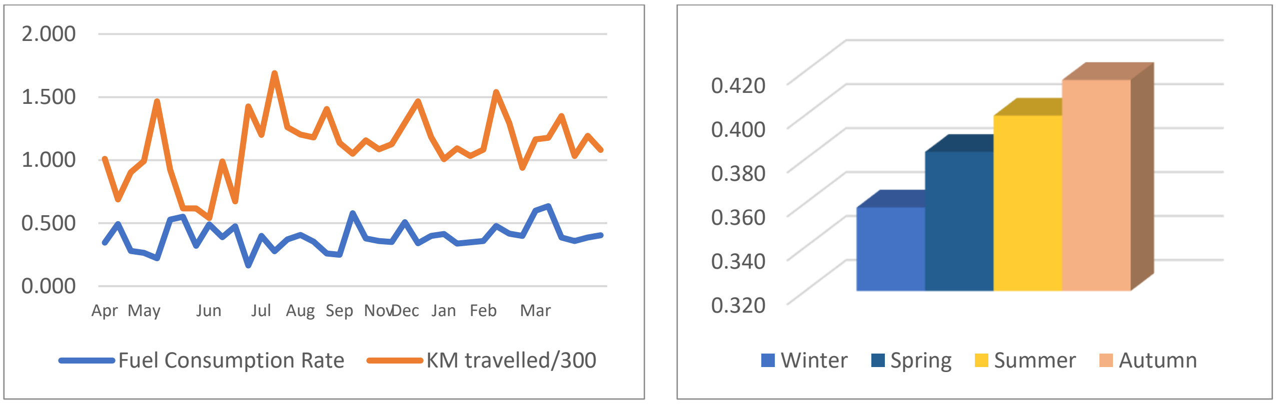
4. Results and Discussions

The results were obtained after establishing all the settings for two pilot trucks, a waste collector and tree maintenance truck, and running the optimization model for both. The total distance travelled, fuel consumption, and GHG emissions, were calculated for the regular routes of pilot trucks, and were compared with their optimized route in the simulation model. First, the fuel consumption rate of both pilot trucks was estimated and they were added to the simulation models.

4.1. Results of Tree Maintenance Truck

4.1.1. FCR Calculation

Figure 21 shows the fuel consumption rate for tree maintenance truck in the period of 2016-2017.



(A) (B)

Figure 21 A) Fuel consumption rate of tree maintenance truck versus kilometers travelled by this truck (l/100km) B) Fuel consumption rate of tree maintenance truck in the four seasons (l/100km)

For simplicity, the kilometers travelled in this figure divided by 300, to compare its trend with the fuel consumption rate. As this figure shows, the fuel consumption rate is not a constant value and has large variance, which does not follow a specific trend. Unexpectedly, the correlation factor between these two series is -0.3373, which shows the negative relationship between kilometers travelled and fuel consumption rate. Therefore, this truck consumes less fuel on mission days with more traveling and less maintenance and it consumes more fuel in the more stop-and-go missions.

This figure also shows the considerable difference between fuel consumption rates in the four seasons. This figure is based on one-year refuel data of the truck; it shows that the lowest rate of fuel consumption is in winter at 0.358 L/km, followed by spring, at 0.383 L/km, and summer, at 0.400 L/km. The highest rate is for autumn, at 0.416 L/km.

Figure 22 shows the details of the fuel consumption rate four seasons. The r-square factor for spring is near zero and for summer is 0.0047. For autumn, this figure is 0.1366 and it is 0.1574 for winter. Therefore, the fuel consumption rate does not follow linear regression. On the contrary, it seems to follow a polynomial trend. For instance, the R-square for polynomial regression of the fuel consumption rate for summer, with order 6, is 0.9247, versus 0.0047 for the linear regression. Thus, the fuel consumption rate of this type of Council truck does not follow the kilometer traveled, and other factors, such as braking processes or maintenance procedures, can affect it.

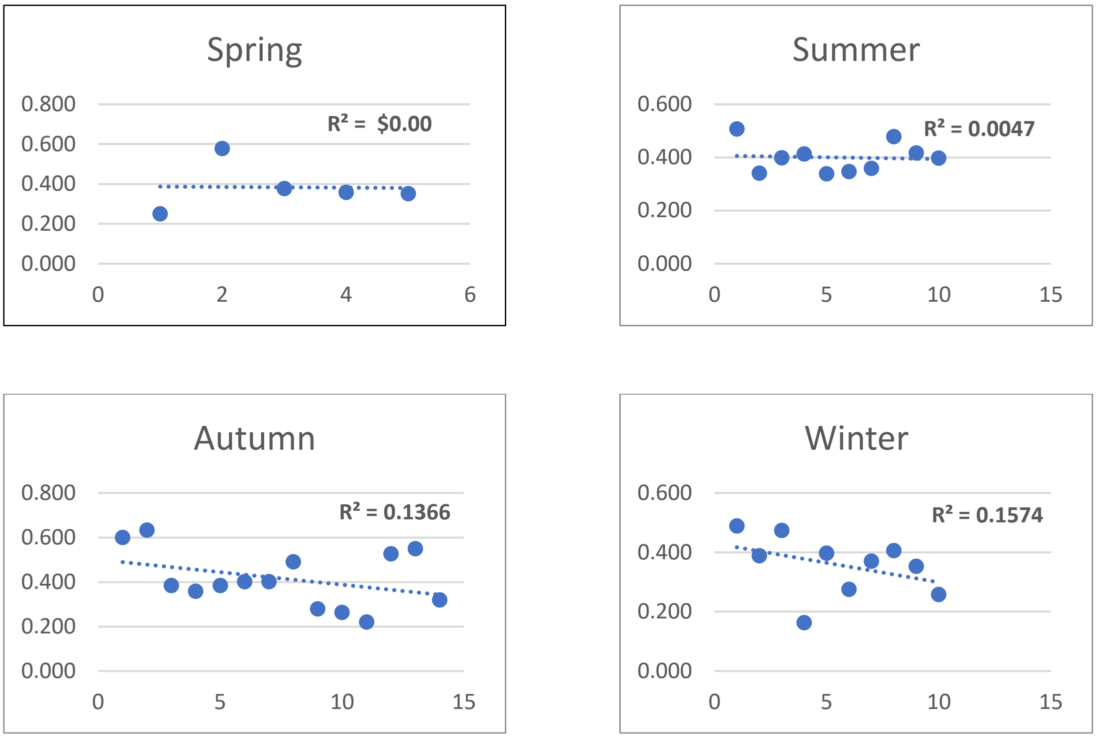


Figure 22 Fuel consumption rate of tree maintenance truck in the four seasons

4.1.2. Route Optimization Results

Figure 23 shows the results for the four random days of the tree maintenance truck. The model used the truck's destinations on those specific days, and re-ordered the nodes according to Dijkstra's algorithm. In the next step, the model found the best route to travel between nodes. The total optimized kilometers are shown in each box.

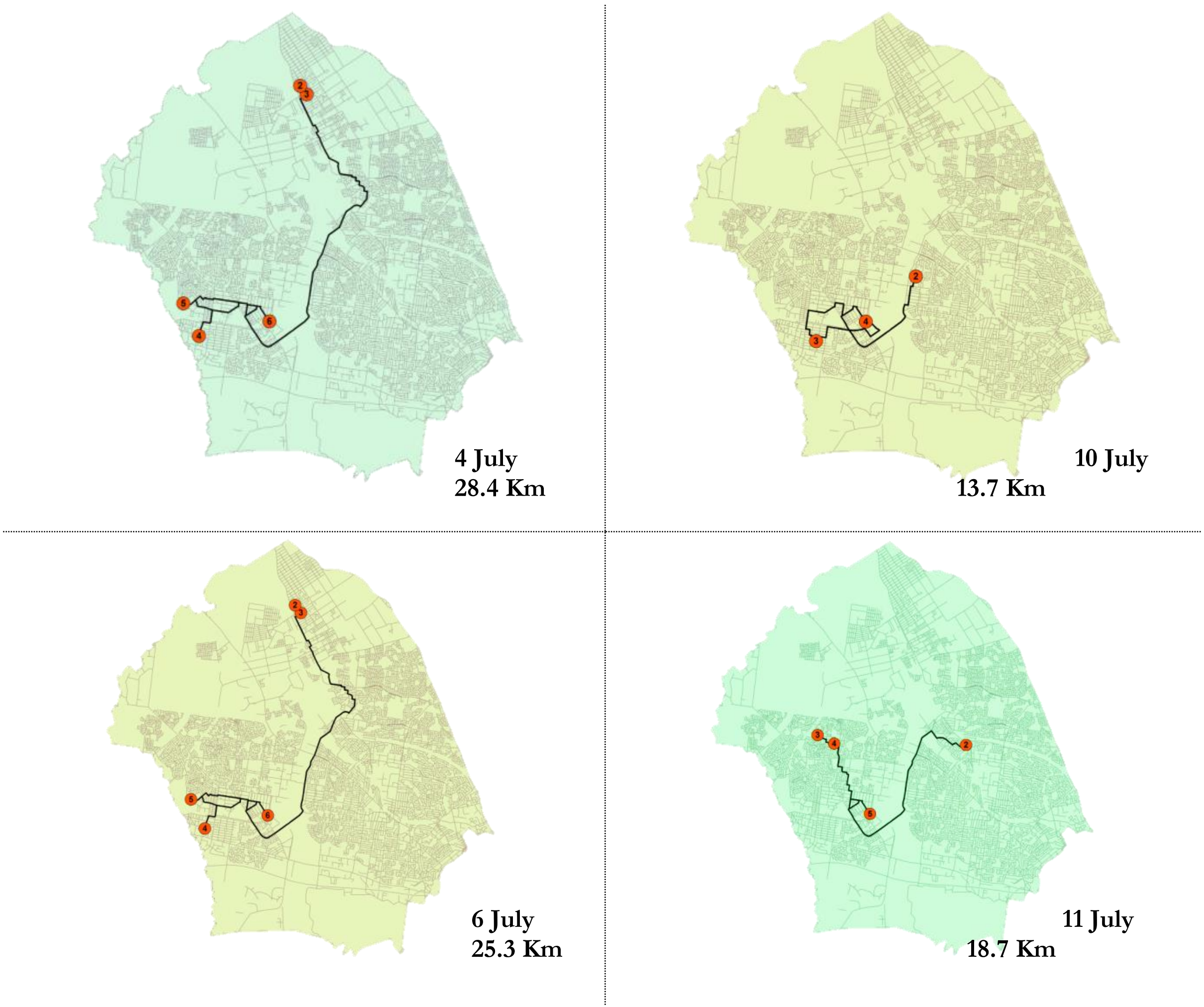


Figure 23 Results of route optimization for tree maintenance truck in four sample days

Figure 24 shows the difference between total actual kilometers and total kilometers travelled by the model. From 1-10th of July the total actual kilometer was 275 km; however, the total distance in the model was 97 km. This result represents a 65% decrease in km. From 10-20th of July, there is 65% decrease in kilometers between the simulated and actual routes, with 81 km in the optimized route than the 230 km actually travelled. The total actual kilometers traveled in July 2016 was 780 km, versus 309 km proposed by the optimization model. The overall distance decrease of 60.38% in the optimized path would save 471 km in the month. In addition, the simulated model shows a considerable difference between actual fuel used and simulated. The actual fuel used was 380 liters in July 2016, versus the simulated figure of 146 liters. Therefore, this shows 62% decrease in fuel usage. In addition, the total actual emissions are around 1.034 tons of carbon dioxide equivalent in July 2016 versus the simulated 0.397 CO2e in the same period. This represents 62% decrease in GHG emissions, which is close to the savings in fuel consumption and distance outlined by the optimized model.

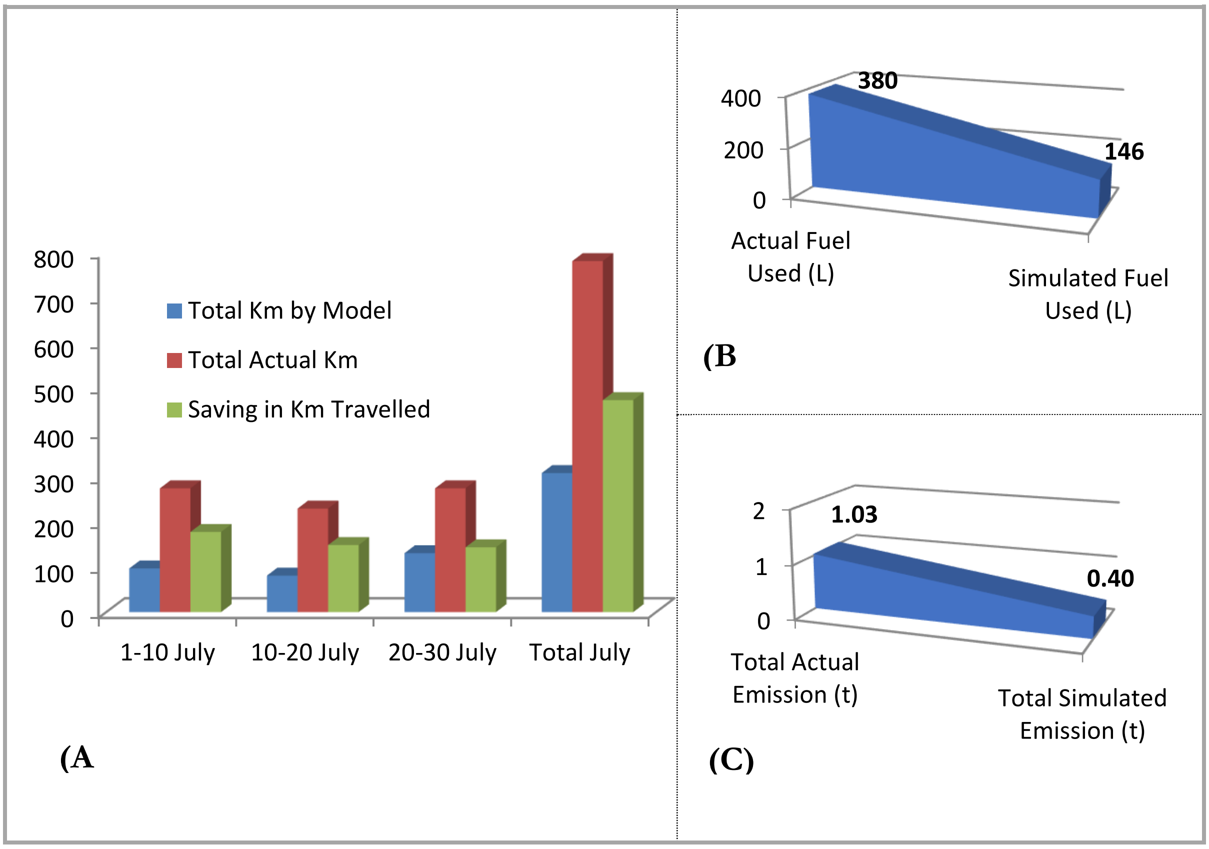


Figure 24 A) Total km travelled by the optimized route versus actual routes for tree maintenance trucks B) Actual fuel used versus simulated for tree maintenance trucks C) Total actual emission versus simulated for tree maintenance trucks

4.2. Results of the Waste Collector Truck

4.2.1. FCR Calculation

As explained in Section 2, the FCR of the waste collection truck is not linear, as it has three different steps during traveling: (1) Traveling outside collection areas; (2) idling in front of each household while waste is loaded; and (3) Traveling within an assigned collection area.

Based on Table 9, the total fuel use of a garbage truck is 16% in idling and 84% in driving. However, driving is categorized into two parts: outside the collection area when the truck is moving and inside the collection area when the truck is stopping and moving at each loading node. Table 10 shows the average kilometers traveled by the pilot garbage truck on each day of the week. The average kilometers travelled by this waste collector inside the collection area, is 36%, with standard deviation 0.02, while the average kilometers travelled outside the collection area is 64%.

Table 10 Share of km traveled by the waste collector truck inside and outside the collection area

	Total Km inside collection area	Total Km outside collection area	% Inside	% Outside
Mon	28	56	34%	66%
Tue	40	74	35%	65%
Wed	53	78	40%	60%
Thu	40	76	35%	65%
Fri	48	91	35%	65%
Average	42	75	36%	64%

In addition, according to Equation 3, the house-to-house fuel consumption rate of this pilot truck is

$$Ht = \frac{81 - (4 \times 2.16) - (90 - 42) \times 1}{42} = 0.58\ L\ km^{-1}$$

Therefore, the average total fuel consumption rate of this truck is as follows:

$$FCR = 0.16 \times 0.58 + 0.84 \times 1 = 0.93\ L\ km^{-1}$$

The result almost corresponds with the long-time fuel usage log from the Council's database.

4.2.2. Route Optimization Results

Table 11 shows the result of the simulation model on the garbage truck for July 2016. As this table shows, the study period has 21 working days. Comparing the total actual kilometers travelled per day with the optimized route, it would save around 10 kilometers per day. This result is based on the average simulated kilometers of around 80 km per day compared with the regular route of about 90 km per day. When multiplying this result by the 21 working days per month on average, the total distance savings would be around 210 km/month.

Figure 25 shows the difference between actual fuels used and the simulated fuel usage, and the actual GHG emissions and the simulated ones. Using the optimized route instead of the regular one, 183 liters of fuel per month can be saved, which is about 11% less in normal fuel use per month. In addition, the total reduction in GHG emissions would be 0.456 tons per month, which is around 10%.

Table 11 Average actual km traveled by the garbage truck versus simulated

No. Working Days July 2016	**Simulated Km on Weekdays**	**Total of the Month**
Mon=4	66.6	266.4
Tue=4	75.9	303.6
Wed=4	87.4	349.6
Thu=4	75.3	301.2
Fri=5	93	465
Average simulated Km per day		**79.64**
Average Actual Km per day		**89.76**

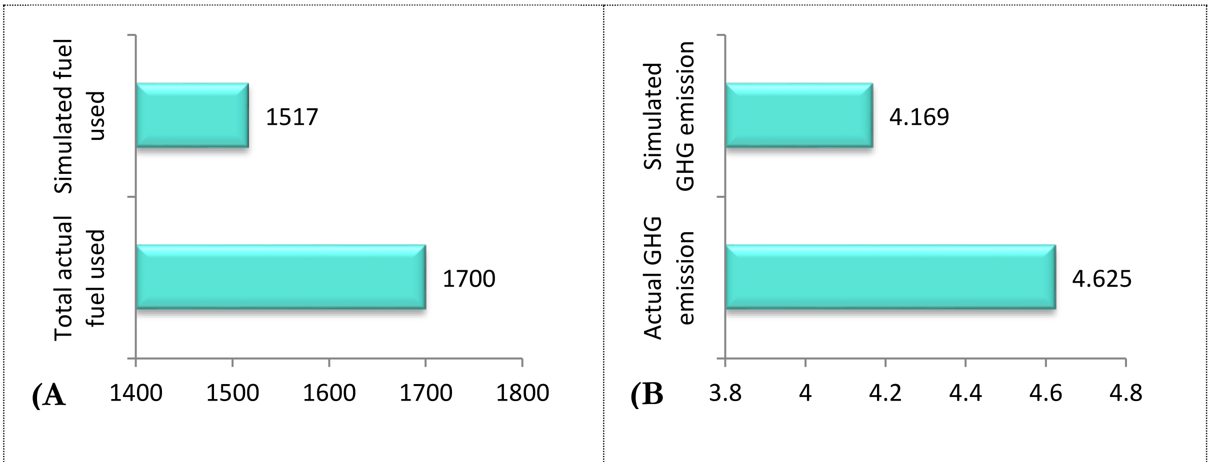


Figure 25 A) Total actual fuel used versus simulated fuel usage in waste collectors B) Actual GHG emissions versus simulated in waste collectors

5. Discussions

Extrapolating the results of one truck to the 100 trucks owned by the Council for the same work types and emissions, we can conclude that using the optimized route can reduce kilometers travelled per month by 49,600 km/month, total fuel consumption by 23400 L/month, and total GHG emissions by 63.1 tons/m. In addition, by supposing the rate of diesel cost at the minimum of $1.18 AUD/month (Australian Competition and Consumer Commission, 2016), it can reduce the cost of fuel by around $28,000 AUD/ month .

The other result of this research was a comparison between the efficiency of tree maintenance trucks with the garbage ones. The results implied that the garbage trucks are much more efficient than the tree maintenance ones, since the difference between the optimized route and regular ones in the garbage truck was about 11% per month; however, the difference for the tree maintenance truck was 61%. There can be several reasons for this: the fixed destinations for garbage trucks unlike the tree maintenance trucks may be one. Waste collectors have fixed nodes to travel each day and they know them before starting the trip; therefore, they could find more efficient routes. Any investment on implementing a smart navigation system on the tree maintenance team or other teams with changing destinations each day would seem to be the most effective in making higher reductions in fuel usage, and thereby, GHG emissions.

6. Summary

In line with designing a carbon reduction toolkit for Blacktown City Council, this part of the research project aimed to quantify the distance driven by the different types of heavy vehicles in the optimized route compared to their regular routes. The purpose of this comparison was evaluating the impact of route optimization of heavy vehicles on fuel consumption and GHG emissions. Two different types of Council trucks were selected: 1) A garbage truck with almost fixed daily destinations and routes, and 2) A tree maintenance truck with the various daily missions and destinations.

The results of this research showed that the total savings in kilometers traveled per month for the tree maintenance truck was 431 km, which equaled a 60.38% decrease in kilometers travelled in the optimized path versus the actual one. In addition, the simulated model showed that the actual fuel used was 380 liters/month; however, the simulated figure was 146 liters/month, which is a 62% decrease in fuel use. In addition, the total actual GHG emissions were around 1.034 tons of carbon dioxide equivalent per month versus 0.397 tCO_2e in the optimized route. This showed a 62% drop in GHG emissions, which is near the saving in fuel consumption and kilometers travelled per month. The results of the study on the waste collector trucks showed that using the optimized route instead of the regular one, can save around 10 kilometers per day. When multiplying this result by the 21 working days per month on average, the total saving in kilometers travelled per month would be around 210 km/m. In addition, using the optimized route would save 183 L of fuel per month, which is about 11% reduction in fuel usage. The total reduction in GHG emissions would be 0.456 tons per month, which is around 10% of the average GHG emitted by this type of truck. The quantification for any type of innovation in reducing GHG emissions in the transportation sector can provide a handy toolkit. This toolkit will help compare the impact of different types of GHG reduction strategies in terms of carbon reduction and the cost of implementation.

Future studies of the same type can focus on evaluating the results of route optimization on heavy vehicle chains. Several trucks in the service center, which do the same tasks within the same boundary, can cover their missions using a smart navigation system. This system connects the trucks and reduces the need for traveling by finding the nearest truck for the requested mission. The fuel consumption formula for the specific trucks is another interesting area that can be worked on. There are several studies on the specific FCR for garbage trucks; however, the FCR for other types of truck such as street sweepers, tree maintenance, pickup trucks, and so on, also can be calculated and modeled.

CHAPTER 6

GHG emission Reduction in Waste Management

SUMMARY

Tis chapter introduces some proposed strategies for GHG emission reduction in waste management. In particular, it investigates cost-efficient solutions for reducing GHG emission from general waste by decreasing waste at the origin point. Furthermore, this chapter proposes a waste management plan for the Council highlighting issues, actions, policy type, and resources required for undertaking action.

1. Introduction

Global municipal solid waste (MSW) amounts to approximately 1.3 billion tons per year and is expected to increase to approximately 2.2 billion tons per year by 2025. MSW can have adverse effects on human health and the environment in different ways. In particular, the disposal of municipal solid waste can have negative impacts on underwater streams, soil quality, and GHG emission on a larger scale. Waste produces a large amount of greenhouse gas emissions, which is the critical issue affecting the change in global climate (S. Lee, Kim, & Chong, 2016; V. W. Y. Tam et al., 2018).

In June 2016, the Department of Sustainability, Environment, Water, Population and Communities in Australia conducted a survey on Waste Generation and Resource Recovery in Australia during 2014/15. The result of this study shows that the amount of waste generated in Australia has been 2.7 tons per capita per year. (Pickin & Randell, 2017). In 2014-15, the total quantity of waste deposited in landfills (excluding fly ash) was about 22 Mt (Pickin & Randell, 2017), which contributes to almost 3% of Australia's total net emissions. Although emissions from this sector are only responsible for a minor portion of Australia's total emissions, the sector provides the opportunity for low cost sources of abatement. The lowest cost GHG reduction opportunity in this sector is decreasing waste from the source points, which this study will investigate.

Reducing waste streams for GHG reduction is not simple. Since any proposed solution for removing one type of waste from the waste stream, will pose another source of GHG emission, which is necessary to consider and calculate. For instance, when removing organic food from the general waste stream and eliminating CH4 emissions because of anaerobic digestion of organic material, another source of GHG emission from the transportation of organic material to the nearest commercial composter will be added to the net GHG emissions. The same scenario is true for removing paper products from recyclable bins by introducing separate bins for paper and cardboard. In this case also, it is necessary to consider and calculate the transportation cost and GHG emissions from burning fossil fuel, which is the topic of this study, the GHG emission analysis of different scenarios for reducing general waste.

The main difference between this study and prior research in this field is the scale and approach of this study. Most prior studies are based on the regional or national scale, examining the decrease in GHG emissions from the waste sector in large scales. However, this study investigates possible pathways to alleviate GHG emissions at the local scale and from initiatives proposed at source points of waste production. Dealing with GHG emissions at this level is also important, because if we can cut emissions at this small scale and repeat it for all public facilities with the same characteristics, it will eliminate further GHG emission from separating waste at transfer or landfill stations (Chung, Paik, & Kim, 2018; Deus, Battistelle, & Silva, 2017; Yili Liu, Xing, & Liu, 2017). This study has been conducted at the local city scale in Australia; however, the comparison method, the methodologies for GHG calculations, and the waste management plans suggested by this study can be utilized and repeated in similar situations around the world.

2. Previous Studies

Several studies investigated GHG emissions from different scenarios of managing waste at the regional or national levels. For example, Ying-Chu Chen and Lo (2016), have investigated GHG emissions from five municipal solid waste treatment scenarios, including landfilling, waste to energy, and material recovery in Taiwan, which is at a much larger scale than this study. Dong, An, Yan, and Yi (2017) investigated greenhouse gas emissions from the waste sector and its projected changes using integrated waste management facilities in Hong Kong. Rajaeifar et al. (2017) made a comparative review of electricity generation and GHG emissions reduction potentials through different municipal solid waste management technologies in Iran using life cycle assessment (LCA).

One of this study's aim is to develop a waste management plan for libraries and aquatic centers operated by Blacktown City Council. One of the main previous studies in this field developed a municipal solid waste management decision support tool for Naples, Italy (Chifari et al., 2017). In this study, a metabolic network theory and multi-scale integrated analysis of societal and ecosystem metabolism were used to generate informed deliberations about policies over Municipal Solid Waste Management. Yoo and Yi (2014) evaluated the solid waste management plans in Seoul, Korea. They categorized waste policy in six stages, including waste reduction, waste recycling, and waste to energy, waste management, eco-friendly waste infrastructure, and climate change, and prepared an action plan for each strategy. Knowles (2009) evaluated and summarized the National Solid Waste Management Plan for Iraq. He reviewed the current solid waste management plans and examined municipal waste management at the local level. Yukalang, Clarke, and Ross (2017) examined current municipal waste management plans in Thailand at the local level, focusing on the Tha Khon Yang sub-district surrounding Mahasarakham University in Mahasarakham Province. Parekh, Yadav, Yadav, and Shah (2015) identified and assigned weight of indicator influencing performance of municipal solid waste management using AHP.

At the city level, most studies have focused on various procedures to reduce the municipal solid waste or on introducing new optimization systems for municipal solid waste management. It can be referred to (Jia et al., 2018; Majumdar & Srivastava, 2012; Mou, Scheutz, & Kjeldsen, 2015; Quiroz-Castañeda, Sánchez-Salinas, Castrejón-Godínez, & Ortiz-Hernández, 2013). For instance, Jia et al. (2018) presented a hybrid approach for planning a carbon-constrained municipal solid waste management system for Qingdao City. They proposed recycling, landfilling, landfill gas (LFG) capturing, and incineration scenarios for reducing the GHG emissions from the waste stream, using Life Cycle Carbon Accounting and Carbon Emission Pinch Analysis.

This research study investigates the different categories of general waste at specific publicly used facilities at the local scale. Searching for new and innovative opportunities for waste reduction, this research was designed and conducted in collaboration with Blacktown City Council. The research study in this section aimed to:

- Investigate and measure the different categories of waste placed red-lid bins as general waste.
- Identify new opportunities for general waste reduction.
- Quantify the potential GHG emission alleviation from each reduction scenario.

As explained previously, the Case study of this project is Blacktown City. With the population growth rate of Blacktown City at around 2.5% in 2016 (id the population experts, 2016) Blacktown City Council will experience an increase in its domestic waste stream over the next few years. In line with Australia's Nationally Determined Contribution to the 2015 Paris Agreement to reduce its total greenhouse-gas emissions by 26-28% below its 2005 level emissions (Australian Government, 2017) Blacktown City Council is working to decrease its GHG emission. This research study will investigate the opportunities for reducing the GHG emissions from the landfilling of general waste from specific public facilities. For this purpose, two different assets of the Council have been chosen, **Blacktown Aquatic Centre** and **Max Webber Library**. Both are large examples of their kind in the city, and represent similar facilities in this city.

3. Material and Methodologies

3.1. System Boundary of this Research

System boundary defines the life cycle stage that should be included in LCA studies. The sustainability assessment should cover the life cycle stages of a product, which includes the greenhouse gas emission in all stages. According to ISO 14067, there are four types of the system boundaries, including (International Organization for Standardization, 2018; Wu, Xia, & Wang, 2015):

- Cradle-to-grave: Includes emission and removal from the full life cycle of a product.
- Cradle-to-gate: Includes emission and removal up to the point that product leaves the company.
- Gate-to-gate: Includes emission and removal from the different organizations in the supply chain.
- Partial GHG emission of products (CFP): Includes emission and removal from a restricted number of isolated stages.

Since the system boundary of this research is restricted to the disposal stage of the products, it is incorporated into the partial GHG emission of products.

Figure 26 illustrates the system boundary of this research. The main components of the waste management hierarchy are as follows: reduce, reuse, recycle, and dispose. Only the first two, reduce and reuse, are included in this research. In addition, this study considers waste collection because of its significant influence on GHG emissions. The data gathered from the case studies shows that 51% of the waste in this area can be reduced or reused and 49% can be recycled or disposed. As the focus of this study is on reducing or reusing the waste from the source point, it will be working on reducing or reusing the organic materials, papers and cardboards, and paper towels. The rest of this study will investigate the impact of reducing the mentioned items in general waste reduction and GHG emissions.

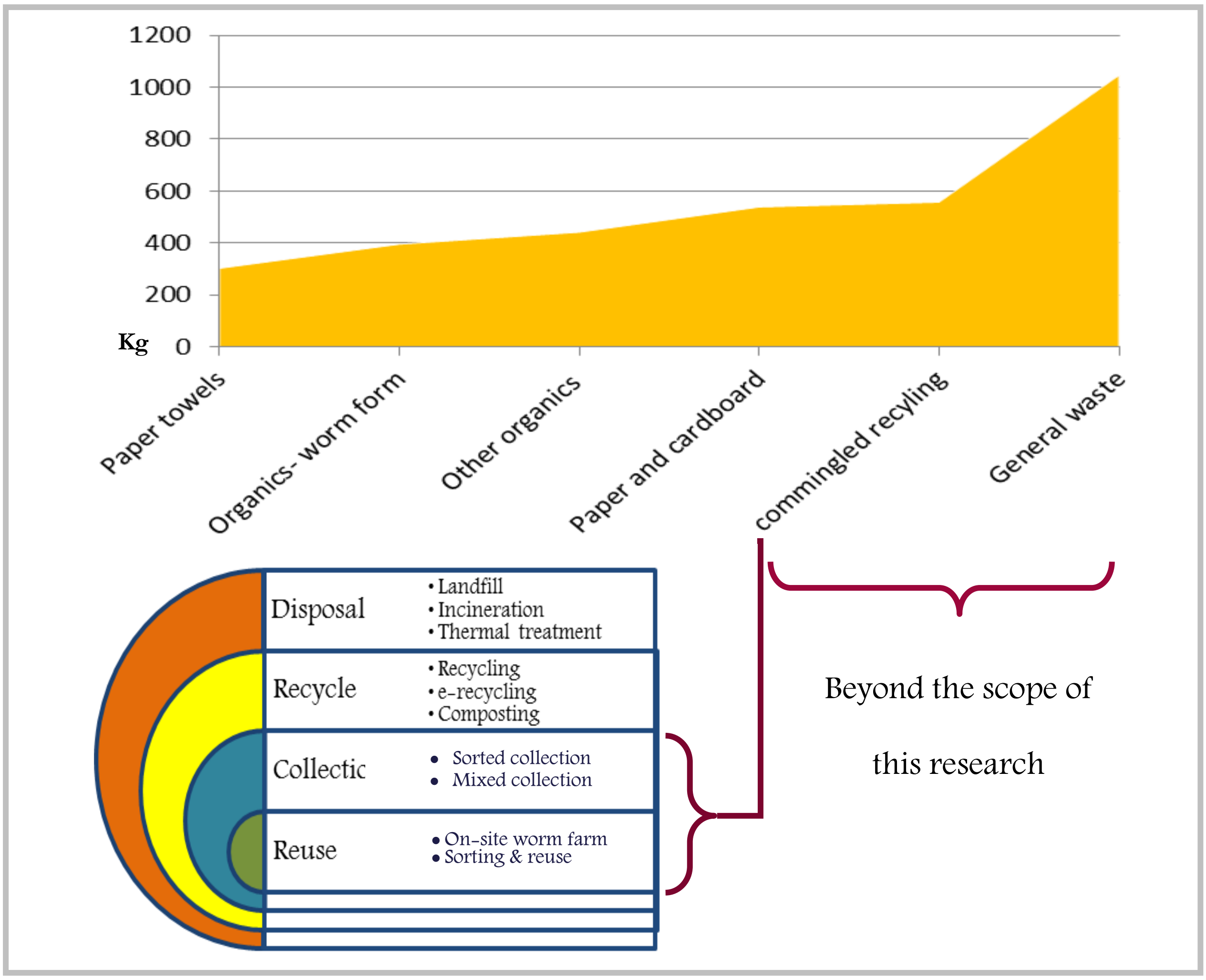


Figure 26: System Boundary of the research

3.2. Baseline of the Waste Stream in the Council's Assets

From June 14 to 19, 2009, McGregor Environmental Services conducted a waste audit of a representative sample of all of the Council's building types for an indication of the amounts and types of waste produced by Council buildings. The building types were:

- Libraries
- Community centers
- Childcare centers
- Depots
- Pools
- Civic centers

This audit will inform strategies to improve recycling and resource recovery at the Council's different facilities. The waste streams investigated were:

- The garbage stream, which is a general waste stream, where no recycling is separated.
- The recycling stream, which is intended for recyclable material placed in yellow-lidded bins for recycling.
- The paper-recycling stream, which is intended for paper products that are not contaminated, and are placed in blue paper recycling bins.

The following sections will summarize the results of this study as a baseline of waste stream in the Blacktown Council's assets.

3.2.1. Childcare center

With regard to child care, 4 centers were audited, John Armitage at Mount Druitt, Goddard Crescent at Quakers hill, Jim Lynch Child Care Centre at Rooty Hill and King's Park Child Care Centre. These were selected, as they were a good representative sample of the different sizes of childcare centers.

The graphs below represent the actual kilograms of each material that the audit measured. The results are presented with recycled or recoverable resources indicated by green actions in the pie charts.

In the pie charts, non-recyclable or recoverable landfill waste is in purple, while organic waste such as food, wood, and garden waste is green, and recyclable waste is yellow. In the charts on waste content of the recycling stream, anything that is not recyclable (yellow) is contamination.

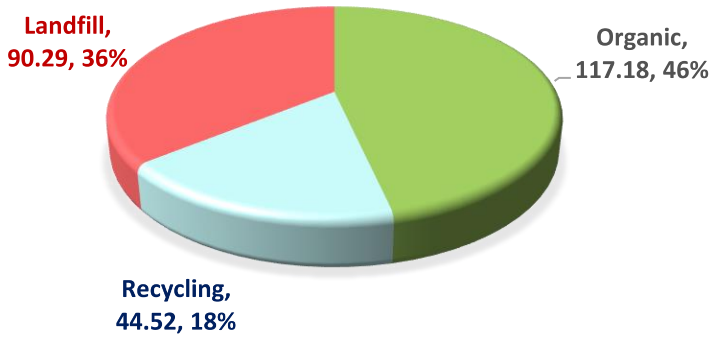


Figure 27: Waste stream in the four sample childcare centers of Blacktown City Council

Figure 27 represents the waste stream in the four sample childcare centers of Blacktown City Council. As this figure shows, of the 252 kg of waste in these four centers in one audit, 117 kg or 46% is organic waste, 18% is recycling waste, and 36% is landfill waste. Therefore, a considerable amount of waste stream in the Council's childcare centers are organic waste and any improvement scenario should concentrate on this organic waste.

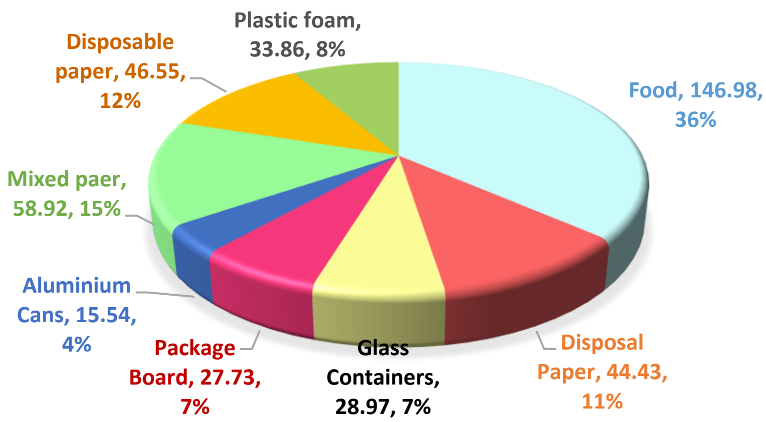


Figure 28: Waste stream in the Council's civic center

Another audited center was the Council's civic center. This center was audited with all other types of Council buildings. As the main center for administrative activities within the Council, and the main workplace for Council within staff, it produces a very high volume of waste, especially paper. Figure 28 represents the waste stream in the Council's civic center. As this figure shows, of the 403 kg of waste in the civic center, the highest volume of the waste is for organic food with 36%, followed by mixed paper with 15% and disposal paper with 11%. Therefore, greater access to recycling bins throughout the building, will be obviously very successful, judging by the amount of paper recycled in the building.

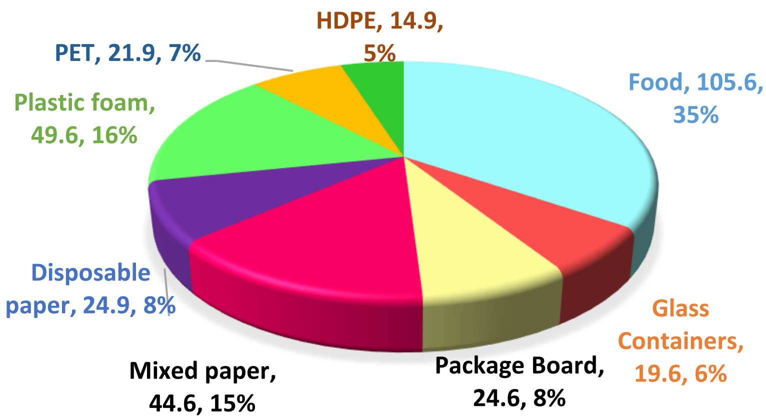


Figure 29: Waste stream of the two selected libraries of Blacktown City Council

Figure 29 illustrates the waste stream of the two selected libraries in the Blacktown City Council. Both the Max Weber Library and Mount Druitt libraries were audited, with Mount Druitt being deemed by library staff to be representative of the size of the other three Council libraries. As this figure shows, of the 306 kg of garbage in these two libraries, organic waste has the largest share in the waste stream with 35%, followed by plastic foam with 16%, and mixed paper with 15%. In terms of libraries, it is discovered no recycling bins, or incorrect use of bins.

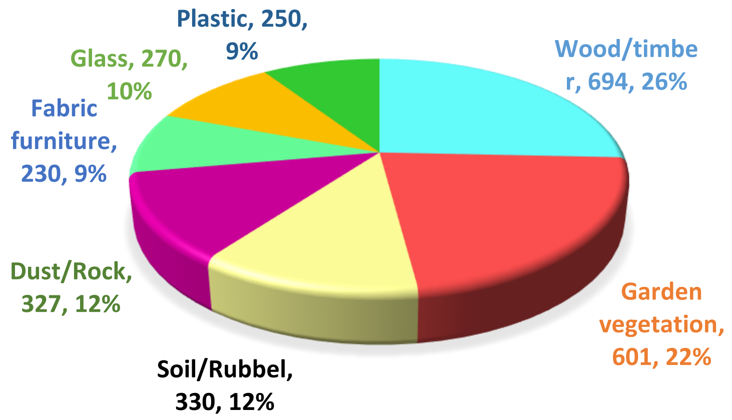


Figure 30: Waste stream of the Council's depot

Figure 30 illustrates the waste stream of the Council depot. The Council depot is a large source of waste, as much of the sorting for Council cleaning operations takes place there and it has a large contingent of staff. It also undertakes the maintenance and repair of some of Council's vehicle fleet. According to Figure 30, of the 2702 kg of the Council's depot waste, the largest share is of garden vegetation with 22%, followed by wood/timber with 26%, and soil and dust, each with 12%.

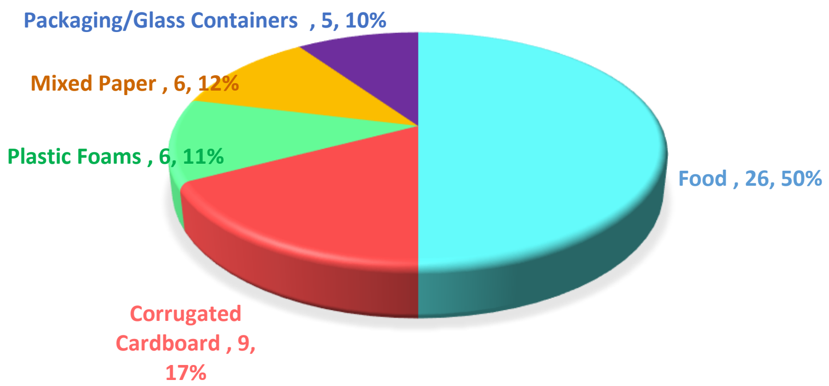


Figure 31: Waste stream of the four sample community centers of Blacktown City Council

Figure 31 illustrates the waste stream of the four sample community centers of the Blacktown City Council. With regard to community centers, Glendenning, Lethbridge Park, Tregear, and Oakhurst community centers were audited, as a representative sample of the 37 community centers that the Council operates.

According to Figure 31, of the 52 kg of waste of these four centers, the largest share is of food waste with 50%, followed by Corrugated Cardboard with 17%, and mixed paper with

12%. Itis suggested investigating the possibility of a worm farm, at least for staff use, or transfer or a collection point for organic waste to transfer to the Council's worm farms.

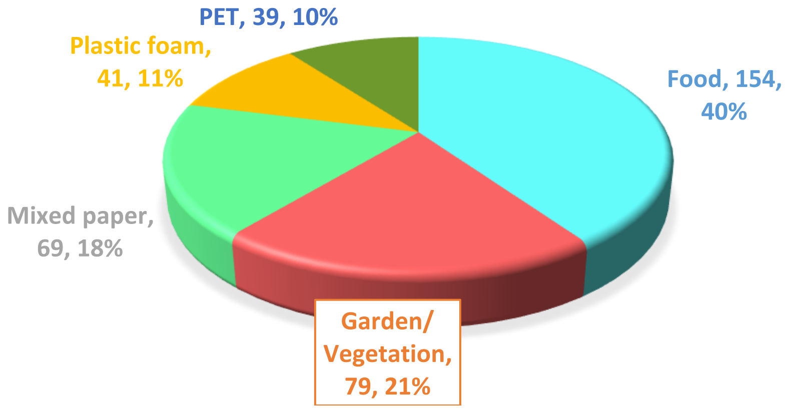


Figure 32: Waste stream of the three sample pools of Blacktown City Council

Figure 32 illustrates the waste stream of three sample pools of Blacktown City Council. In this survey, the following three pool complexes were audited: Blacktown Leisure Centre, Blacktown Aquatic Centre, and Emerton Leisure Centre, along with samples of other types of Council buildings. According to Figure 32, of the 382 kg of total waste in these three pools, the largest share is of food waste with 40%, followed by garden/ vegetation waste with 21%, and mixed paper with 18%.

3.3. Impact Assessment of the Disposal of Municipal Solid Waste

Based on the requirements of the ISO 14067, the following steps are necessary for the calculation of the GHG emission of the products (Hong Kong Polytechnic University, 2015):

1. Project team establishment
2. Define life cycle inventory settings
3. Prepare life cycle inventory
4. Life cycle impact assessment
5. GHG emission study reporting
6. Set reduction strategy
7. GHG emission communication

In this study, It is focused on step 4 for life cycle impact assessment of products in their disposal stage and proposed several reduction strategies, which the Council can authorize. Since It will be focusing on the disposal stage of the product life cycle, the emission factors are used to calculate the process/ product GHG emission. Three main processes for disposal of MSW have been considered in this study with their associated GHG emission, including Landfilling, Electricity usage, and Waste transportation. The related emission factors and the associated formula are used to calculate the GHG emission for each of these procedures.

3.4. Comparison Method

This study investigates and compares the GHG emissions resulting from three potential waste reduction scenarios, with the GHG emissions resulting from landfilling such waste (Mohareb, MacLean, and Kennedy 2011).

Figure 33 shows the comparison methodology used in this study. Any of the potential scenarios would reduce the amount of landfilled waste. However, they could only provide carbon abatement if their GHG emissions were lower than the landfill baseline scenario.

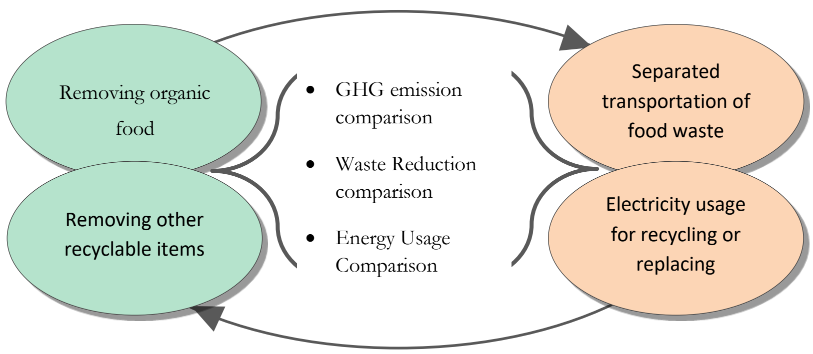


Figure 33: Comparison method for different scenarios of waste reduction in public facilities

3.5. Data Collection

Waste audits were used to estimate the amount of general waste produced in these public facilities. The Council trucks collect municipal solid waste every two weeks in the pilot areas. Therefore, the audit was conducted in the four sample weeks of the selected pilots representing the whole year. The audits were done a day before the collection day to ensure that the bins are almost full or at maximum capacity. There were two types of bins in the study area, General bins, and Recycle bins, which were audited and weighted. There was no hazardous waste in the waste stream in the studied pilots. The systematic process of waste audit is illustrated in Figure 34. The waste categories used in the audit are as follows:

- Recyclables are materials that can be recycled using the Council's existing recycling system and were included:
    - Paper and cardboard
    - Plastic bottles and containers
    - Steel and aluminum cans
    - Glass bottles and jars
    - Plastic bags and packaging
    - Coffee cups
- Compostable materials are mainly organic food scraps, some of which are suitable for worm farming. Items that can be commercially composted but are less suitable for worm farming include highly acidic items, for example, citrus fruit, and items that tend to attract vermin before the worms can process them, for example, fish, meat, and dairy products, which can be categorized as
    - Organic food suitable for worm farms
    - Organic food unsuitable for worm farms
- Unrecoverable materials cannot be composted, and the Council does not have a recycling system for such materials:
    - Diapers
    - Clothing
    - Polystyrene foam packaging
    - Polystyrene foam meat and food trays
    - Other general waste

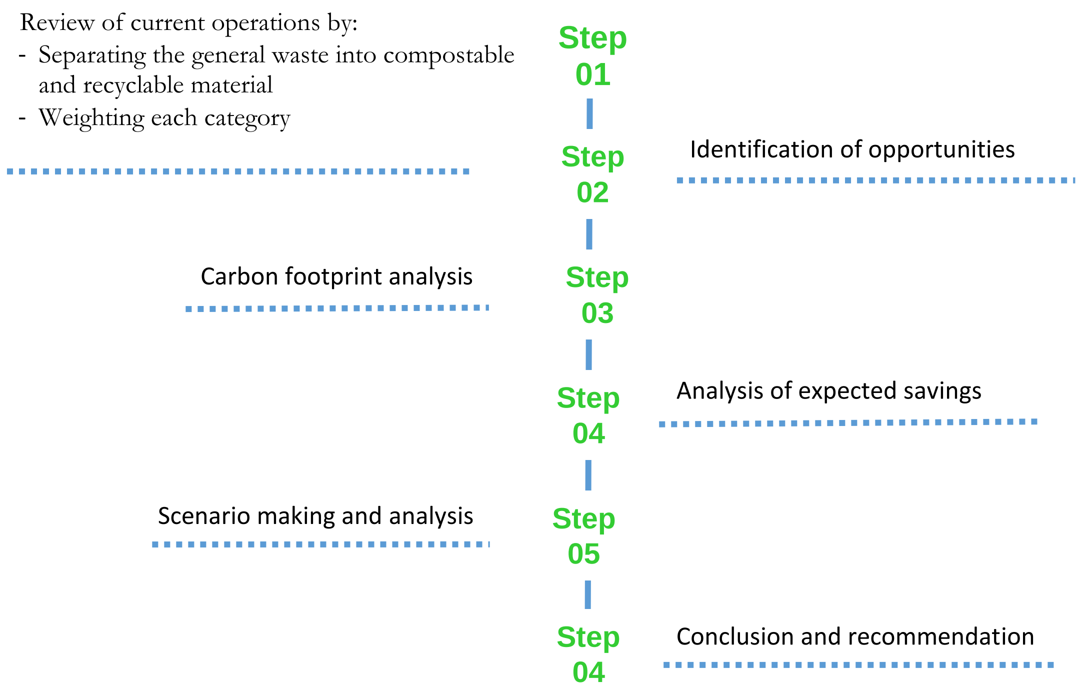


Figure 34: Step-by-step process of waste audit by the candidate

The audit aimed to identify materials in each waste stream that

- Should be in another stream for recycling
- Should be in the garbage stream because they cannot be recycled or composted
- Are contaminating the material in the recycling stream, which can prevent it from being recycled.

The main outcome from this audit is the development of a waste management plan and a program of action to increase the amount of material placed in the correct waste stream, reduce contamination of the recycling streams, and improve the recovery of resources in Council buildings.

3.6. Greenhouse-Gas Emissions from Landfill

When solid waste (SW) is disposed in landfills, most of the organic material will be degraded over a period, ranging from less than one year to 100 years or more. The majority of this process will be bio-degradation. Depending on conditions at the site, this biodegradation will be aerobic or anaerobic. The main degradation products are carbon dioxide (CO2), water, and heat for aerobic degradation, and methane (CH4) and CO2 for anaerobic degradation. The CH4 produced and released into the atmosphere contributes to global warming and it is necessary to estimate and report the emissions in national greenhouse gas inventories under the United Nations' Framework Convention for Climate Change (UNFCCC). The CO2 produced originates from biogenic sources (e.g., food, garden, paper, and wood waste), and therefore, the emissions need not be considered in national inventories (UNFCCC, 2000). This study used the following method to calculate the CH4 resulting from the landfilling of solid waste (Jensen & Pipatti, 2001):

$$\boldsymbol{Methane\ Emission}\left(\frac{\boldsymbol{Gg}}{\boldsymbol{yr}}\right) = \boldsymbol{MSWT} \times \boldsymbol{MSWF} \times \boldsymbol{MCF} \times \boldsymbol{DOC} \times \boldsymbol{DOCF} \times \boldsymbol{F} \times \left(\frac{\boldsymbol{16}}{\boldsymbol{12}} - \boldsymbol{R}\right) \times (\boldsymbol{1} - \boldsymbol{OX})$$

Equation 4: Formula for calculating the CH4 emission resulting from the landfilling of municipal solid waste

Where

- *CH4 Emissions from Solid Waste Disposal*
- *MSWT: total MSW generated (Gg/yr)*
- *MSWF: fraction of MSW disposed to solid waste disposal sites*
- *MCF: methane correction factor (fraction)*
- *DOC: degradable organic carbon (fraction) (kg C/ kg SW)*
- *DOCF: fraction DOC dissimilated*
- *F: fraction of CH4 in landfill gas (IPCC default is 0.5)*
- *16/12: conversion of C to CH4*
- *R: recovered CH4 (Gg/yr)*
- *OX: oxidation factor (fraction – IPCC default is 0)*

3.7. Greenhouse-Gas Emissions from Electricity Usage

Proposing scenarios for alleviating GHG emissions in waste management is a challenging task. While on one hand, removing some specific materials from the waste stream would lessen GHG emissions from their landfilling, on the other hand, it may pose another source of GHG emissions from transportation, recycling, or burning of that particular material. Therefore, when suggesting a practical solution for removing a waste category from the landfill, it is also necessary to calculate the related GHG emissions as the result of processing. One possible replacement source of GHG emissions is electricity usage. Electricity is necessary for processing a particular source of waste for recycling or recovery. Equation 2 can be considered for calculating the electricity usage or performance of the recycling plant (Australian Government, 2015).

$$Y = Q \times \frac{EF}{1000}$$

Equation 5: Formula for calculating the GHG emission from electricity usage

Where

- *Y is the scope 2 emissions measured in CO2e tons.*
- *Q is the quantity of electricity purchased (kilowatt hours).*

3.8. Greenhouse-Gas Emissions from Transportation

The transportation of a particular source of waste to the recycling, recovering, or burning facilities could be another source of GHG emissions in the waste management process. GHG emissions from MSW transportation primarily result from energy consumption for compacting and moving MSWs (Eisted, Larsen, & Christensen, 2009). The diesel consumption per tonne of MSW collected depends on several factors, including types of waste, collection area, types of trucks, distance, and driving behaviors (Karimipour, Tam, Burnie, & Le, 2017). The following formula can be used for calculating the GHG emission from burning fossil fuel for the transportation of waste in heavy trucks (Department of the Environemnt, 2015):

$$Eij = \frac{Qi \times ECi \times EFij}{1000}$$

Equation 6: Formula for calculating GHG emission from combustion of fossil fuel

Where

- *Eij is the emissions of gas type (j), carbon dioxide, methane, or nitrous oxide, from fuel type (i) (CO2e tons);*
- *Qi is the quantity of fuel type (i) (kiloliters or gigajoules) combusted for transport energy purposes;*
- *ECi is the energy content factor of fuel type (i) (gigajoules per kiloliter or per cubic meter),*
- *EFij is the emission factor for each gas type (j)*

3.9. Development of a Waste Management Plan

Long-term planning for solid waste management (SWM) is essential for efficient, reliable, and cost-effective services for MSW. With increasing global concern for climate change, the consumption pattern and disposal of MSW should also change (Yoo & Yi, 2014). To reflect this trend, most Australian cities are developing a waste management plan using a combination of theory and practice. A basic waste management plan should consist of type of waste, any sort of waste reduction scenario, waste recycling plan, waste to energy opportunity, and finally, a plan for disposal of garbage. In addition, it is important to investigate the effect of each proposed scenario on GHG emissions and waste reduction. This is the approach of this research study in proposing potential applicable scenarios for reducing the waste stream and calculating the associated GHG emission reduction.

4. Results

Figure 35 indicates the waste stream in kilograms per week for Blacktown Aquatic Centre and Max Webber Library. According to this figure, the total waste in the aquatic center is two times higher than at the Max Webber Library with 40.95 Kg/w against 21.05 Kg/w, respectively. The other difference between the waste streams in these two centers is in their waste types. These differences are highlighted in Figure 36.

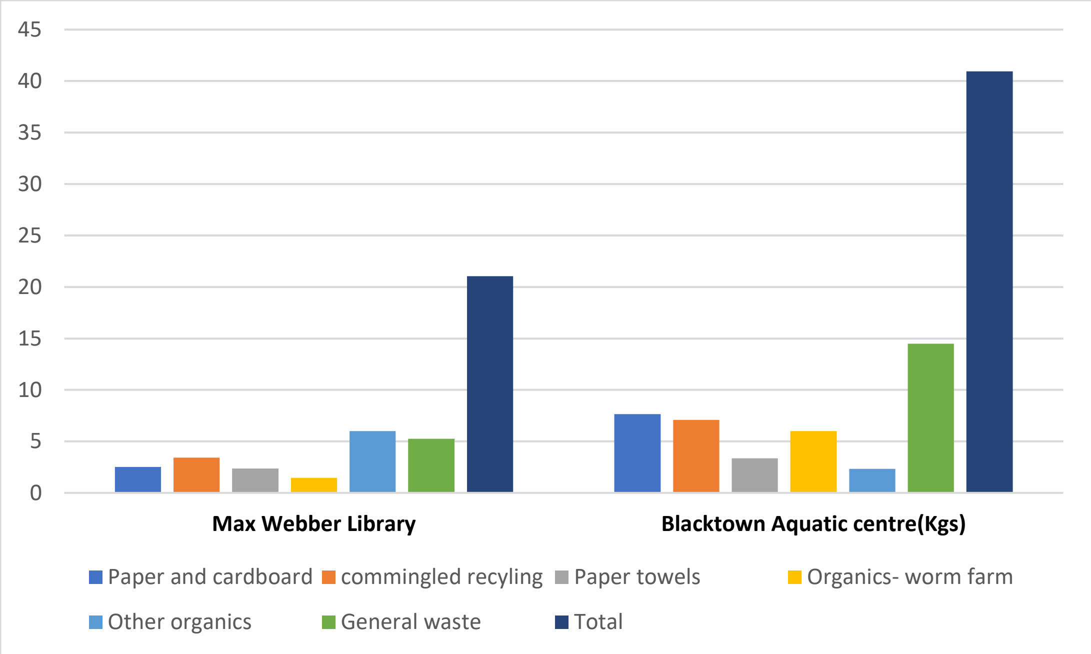
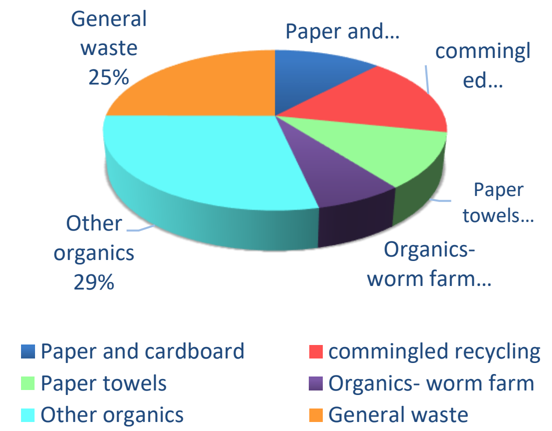


Figure 35: Waste Stream of Max Webber Library and Blacktown Aquatic Centre

The percentage of paper and cardboard in the aquatic center is higher than in the library with 19% (7.65 kg/w) against 12% (2.53 kg/w), respectively. This difference is probably because of the blue bins at the Max Webber library, which provide a separate container for the specific collection of waste paper and cardboard. The total percentage of organic waste, including that suitable for a worm farm and other organic materials are higher in the Max Webber library than the aquatic center at 36% (7.47 Kg/w) against 21% (8.35 kg/w), respectively. This difference might be because of the library's adjoining private coffee shop, which uses the library's general waste (red-lid) bins.

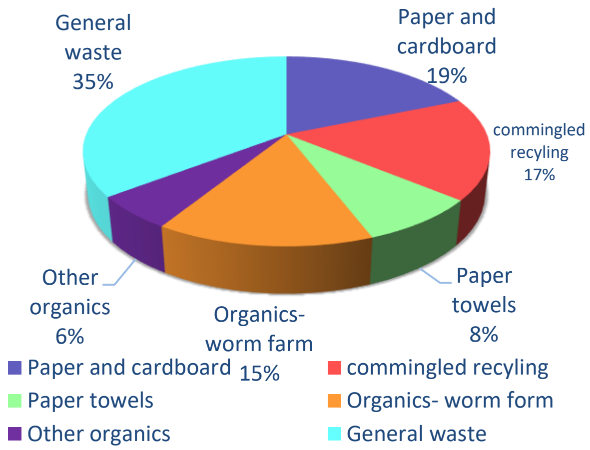
The proportion of paper towels is similar in both centers, with 11% (2.38 kg/w) at Max Webber library and 8% (3.35 kg/w) in Blacktown Aquatic Centre. Commingled recycling is also almost identical in both centers with 16% (3.43 kg/w) in the library against 17% (7.1 kg/w) in the aquatic center. However, the share of general waste is much higher in the aquatic center than the library at 35% (14.5 kg/w) against 25% (5.25 kg), respectively. This was due to nappies, some clothing, and other hygiene items in the aquatic center bins, which were not present in the library.

Max Webber Library



Waste Type	Weight (kg/y)
Paper and cardboard	134
commingled recycling	182
Paper towels	126
Organics- worm farm	78
Other organics	318
General waste	278
Total	**1116**

Blacktown Aquatic Centre



Waste Type	Weight (kg/y)
Paper and cardboard	405
commingled recycling	376
Paper towels	178
Organics- worm farm	318
Other organics	125
General waste	769
Total	**2170**

Figure 36: Waste categories at Max Webber Library

5. Discussion

This section discusses the possible scenarios for reducing the general waste at both centers.

5.1. Removing organic food from the waste stream

One potential opportunity for reducing waste would be removing the substantial proportion of organic materials by encouraging people to use separate "green" bins and sending the organic waste for composting (Weitz et al. 2011). Table 12 shows the potential GHG savings. The potential annual reduction would be 0.161 tons of carbon dioxide equivalent (tCO2e) per year for these two facilities combined. The Council has five aquatic centers and five libraries. Assuming the waste streams are similar across centers, the total reduction of landfill waste GHG emissions would be 0.805 t CO2e per year.

An additional garbage truck could collect the compostable materials from the green bins from the 10 centers once a week and take it to a commercial composter; however, the truck would burn fuel, creating additional GHG emissions. Equation 6 was used to calculate the truck's emissions. The Network Analyst tool in Arc GIS 10.3 was used to estimate the distance the truck would need to travel. The Network Analyst tool allows the user to find the shortest route passing through the defined nodes. Network Analyst in Arc GIS showed that the truck would need to travel 62 kilometers (km) per week. Figure 37 illustrates the location of the public libraries and aquatic centers and the optimized route.

Table 12: Investigated scenarios and their potential landfill waste and GHG reductions

Row	**Scenario**	**Combined weight from both centers (kg/year)**	**CH_4 emissions reduction (kg/year)**	**CO2e reduction (ton/year)**
1	Remove food from waste stream	839	6.42	0.161
2	Remove paper towels from the waste stream	303	4.47	0.112
3	Remove coffee cups from the general waste stream	214	2.22	0.055
4	Remove plastic bags from the general waste stream	220	_	_

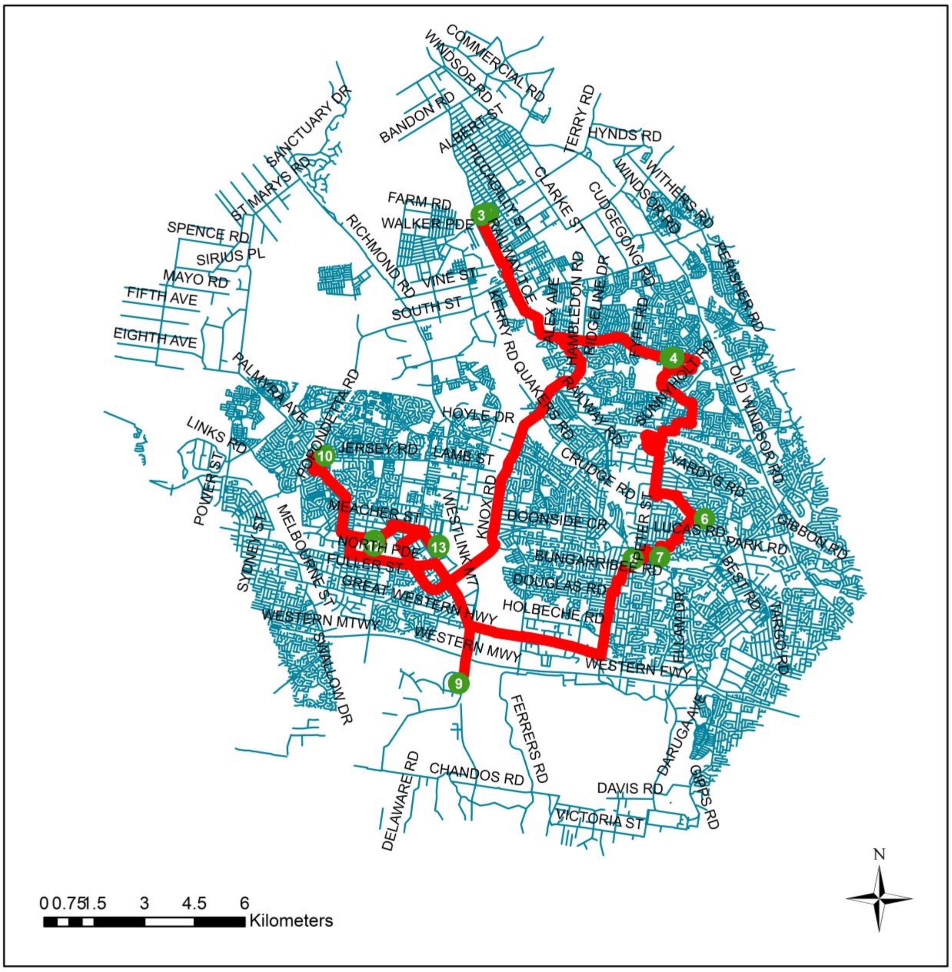


Figure 37: Locations of Blacktown City's public libraries and aquatic centers and the optimized routes to connect them

Assuming that the average fuel consumption of the waste collection truck is equal to 1 liter per kilometer (Nguyen & Wilson, 2010), the annual fuel consumption for this scenario of organics waste collection and its GHG emissions would be as follows:

*Annual kilometers traveled = 62 (km/week) * 53 (weeks/year) = 3286 km/year*

In this scenario, the fuel consumption for the truck would be 3286 liters per year. The truck's emissions from this fuel would be 7.13 t CO2e per year, calculated using Equation 6. Therefore, sending the organics stream for commercial composting separately would increase GHG emissions by a factor of nearly 8.8 over the current landfilling scenario, which is not appropriate.

However, if the variables were to change, there might be a point where a separate collection for organic food waste would result in fewer GHG emissions than landfilling. For example, this might be an appropriate option when the collection happens from more facilities and/or those with higher levels of food waste. The proximity of the facilities to one another and the commercial composter would help optimize this situation.

It is investigated the point at which separate collection for organic food waste offered GHG abatement. Using Equation 4 and Equation 6, and adjusting the equation's pre-defined factors with those suitable for Australia, the equivalent GHG emissions level was determined for landfilling organic waste and for waste transportation. This is shown in Figure 38. Separately collecting organic food waste would result in fewer GHG emissions than landfilling that waste, when the weight of organic food waste is more than 1 tonne and the total kilometers traveled for collection is equal to or less than 100 kilometers.

MSW process	**Equivalent CO_2 emissions**
GHG from the disposal of 4.2 tons of organic food waste	0.81
GHG from 3286 km traveling for collecting the MSW	7.13

Figure 38: Equivalent amount of GHG emissions in waste transportation versus organic waste disposal

Equation 7 generalizes the results of this study for almost all similar sites. According to this formula, separating the organic food from the waste stream would be beneficial for the environment from the GHG emissions perspective if Z is equal or less than 100 km/ton. For any amount of Z more than 100 km/ton, landfilling the organic food is still of more benefit than sending it to the commercial composter.

$$Z = \sum \frac{k_{ij}}{T_i}$$

Equation 7: Formula indicating whether separating organic food is beneficial for the environment

Where

- *Z is the indicator determining the suitability of separating organic food from the waste stream for the environment (for any amount of Z higher than 100 introducing organic food bins is not beneficial for the environment.*
- *k_{ij} is the kilometer traveled between point i and j for collecting the green bins at each point in km/day*
- *t_i is the weight of organic food collected at point i in ton/day*

Another way to remove the organic food from the waste stream is introducing an on-site worm farm. This innovation will remove the organic food from the waste stream without imposing another source of GHG emission. The center's staff could manage the on-site worm farm and the products could be used for the needs of the centers. There can be some people-related issues with an on-site worm farm in a governmental building which can be investigated in a separated study.

5.2. Removing paper towels from waste stream

A second opportunity for reducing waste to landfill would be to remove the paper towels used in the facilities' bathrooms. This could be done by replacing them with energy efficient hand dryers. However, hand dryers would create GHG emissions from electricity consumption. Assuming the number of hand dryer activations was 300 per center per day, and 12 seconds for each activation, the emissions would be 0.490 tCO2e per year, per center. This assumes that electricity would be drawn from the NSW electricity grid, and therefore, would be largely coal-fired. Removing paper towels from the waste stream would reduce GHG by almost 4.47 kg of CH_4 per year per center, which is equivalent to 0.112 t CO2e per year, per center (Climate Change Connections, 2016). Therefore, replacing paper towels with hand dryers would not provide emissions reduction. Using dryers would emit almost four times more GHG than the landfilled paper towels. The results are shown in

Figure 39. The total reduction in GHG emissions of landfilling paper towels is shown in Table 13.

Process	Equivalent CO_2 emissions (tons/year)
Disposal of paper towels for three centers (almost equal to 1 tonne of paper towels per year)	0.36
365000 activations of hand dryers required for 3 centers per year (Activation time: 12 seconds per use)	1.47

1000 activated hand dryers	≈	**Disposal of 4.08 tons of paper towels**
1.47 tCO2e/year		**1.47 tCO2e/year**

Figure 39: Equivalent amount of GHG emissions using hand dryers versus disposal of paper towels

5.3. Removing coffee cups from waste stream

An additional opportunity for reducing waste in landfills would be to separate coffee cups and plastic bags from the general waste stream (RTI International, 2010). Recycling of coffee cups is now becoming easier in Australia with the introduction of facilities that can separate the plastic lining from the base cup. To recycle coffee cups effectively, they need to be collected as a clean waste stream. There could be designated collection tubes and bins, and partnering with existing services to collect the cups (Simply Cup, 2017). Similarly, plastic bags and other soft plastics can be separated using dedicated bins, and partnering with a larger existing program operating in Australia, such as the "REDcycle" program, which collects and recycles post-consumer soft plastic (REDCycle, 2017).

In this scenario, it is assumed that GHG emissions for the separate collection of cups and plastic bags would be minimal, as the collection vehicles would be visiting nearby facilities as part of their existing collection. The results of removing coffee cups and plastic bags from the waste stream are shown in Table 13.

5.4. Removing Plastic Bags from Waste Stream

The final recommendation is for reducing general waste by separating plastic bags from the general waste stream by introducing small, dedicated soft plastic waste bins. These could provide collection points for the "REDcycle" program. The RED Group, which is a consulting and recycling organization based in Australia, has developed and implemented the REDcycle Program; a recovery initiative for post-consumer soft plastic. The RED Group has teamed up with some of Australia's largest supermarket chains to make it easy for customers to keep their plastic bags and soft plastic packaging out of landfills (REDCycle, 2017). This program allows the collection of plastic bags and transportation to recycling facilities in Australia, which could be beneficial for the environment. The related GHG emissions from fuel consumption of the collection trucks can be simulated in other research if the location of the collection points is available. The results of removing plastic bags from the waste stream are shown in Table 13.

Table 13: Results of implementing different scenarios for reducing general waste on GHG emission reduction at Max Webber Library and Blacktown Aquatic Centre

Row	Initiative	Total weight in both centers (kg/year)	CH4 emission reduction (kg/year)	CO2e reduction (ton/year)
1	Removing food from waste stream	839	6.42	0.161
2	Removing paper towels from the waste stream	303	4.47	0.112
3	Removing coffee cups from the general waste stream	214	2.22	0.055
4	Removing plastic bags from the general waste stream	220	–	–

As discussed above, separating a particular type of waste from the landfill stream and treating it differently may cause GHG emissions from that alternative treatment. For example, when the alternative treatment of recycling requires additional waste collection trips, the emissions from recycling may be greater than from landfilling. On the other hand, recycling, composting or even burning of some types of waste will reduce the ecological footprint more than landfilling that waste. The question is: what is the optimum point between having a lower ecological footprint, but higher GHG emission, and visa versa. Future studies can investigate this issue. Figure 40 illustrates the graphical scheme of the suggested scenarios for reducing GHG emissions from waste stream in this research.

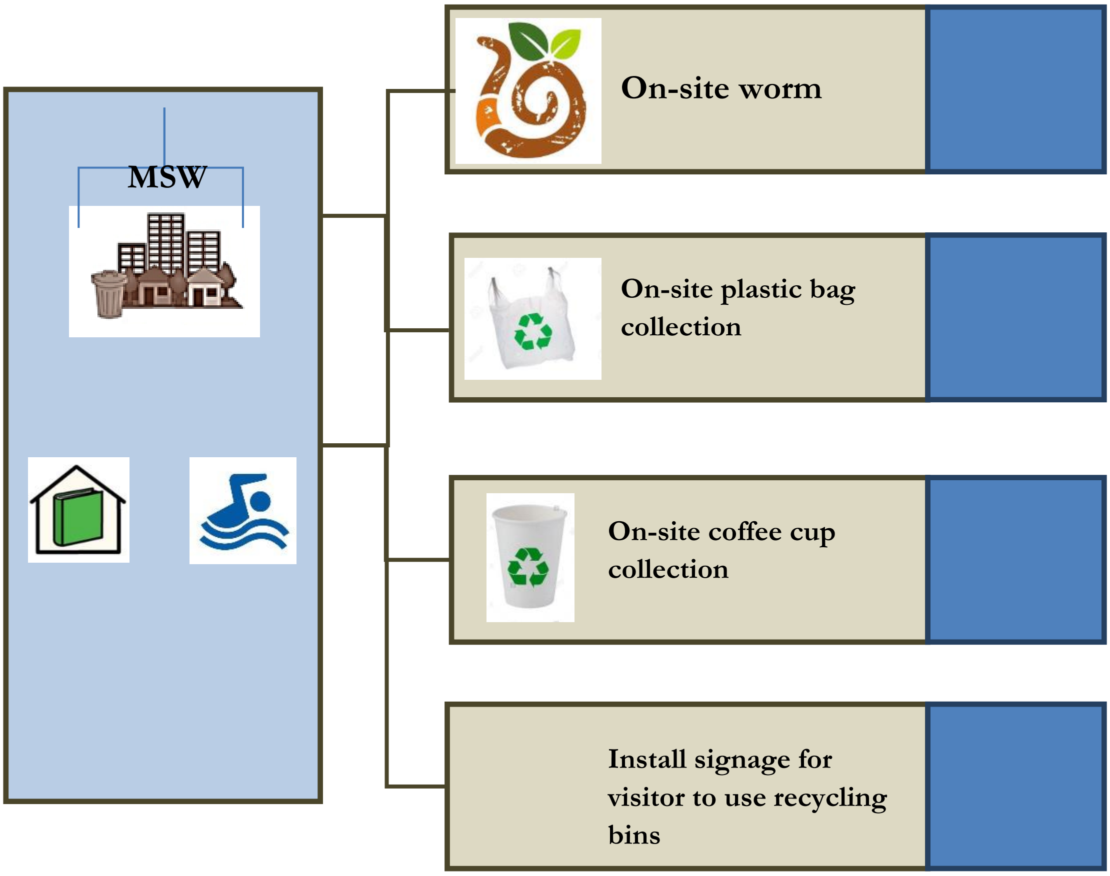


Figure 40: Graphical scheme of the suggested scenarios

5.5. Removing organic food waste from the landfill stream.

Equation 8 has been developed to help generalize the results of this study for similar sites across Australia. Separating and transporting organic food waste from the landfill stream would reduce GHG emissions compared with landfilling that takes waste only equal or less than 100 km/ton. However, when Z is greater than 100 km/ton, landfilling organic food waste is the better option for minimizing GHG emissions.

$$Z = \sum \frac{k_{ij}}{T_i}$$

Equation 8

Where

- *Z (km/ton) is the indicator determining the suitability of separating organic food waste from a landfill stream for GHG reductions. (If Z is found to be greater than 100, there is no such benefit.)*
- *k_{ij} is the kilometers traveled between points i and j to collect organic food waste, in km/day.*
- *t_i is the weight of organic food waste collected, in tons/day.*

An alternative way to remove organic food waste from the landfill stream without imposing another source of GHG emissions would be to introduce an on-site worm farm. The center's staff could manage the worm farm and the products could be used for the needs of the centers.

Removing paper towels from the waste stream. This study found that removing public facility paper towels from bathrooms and replacing them with hand-dryers would emit almost four times the level of GHG compared with landfilling paper towels. Therefore, currently, using paper towels is a better option in terms of GHG emissions. However, hand dryers might become the better option if their associated GHG emissions were reduced by a factor of 4 or operated by the solar panels. This might occur through highly efficient hand dryers and/or increases in the renewable energy proportion of the required electricity.

Removing plastic bags and coffee cups from the waste stream. This study found that removing plastic bags and coffee cups would reduce GHG emission when public facilities partner with larger schemes that collect and recycle the items. This is possible in Australia through existing programs such as REDCycle and Simply Cups. Proximity to other facilities using the program and to the relevant recycling center would optimize this option.

5.6. Developing a Waste Management Plan for the SPECIFIED Public Facilities

Table 14 is a summary of the waste management plan for public facilities in Blacktown city. This table illustrates the proposed plans for reducing the general waste stream in Blacktown City's libraries and aquatic centers. According to this table, the issues related to high amounts of paper products or other recycling materials in garbage stream could be addressed by installing signage to encourage greater use of recycling bins. Providing access to on-site worm farms can address very high occurrence of food waste in garbage. Issues related with the high volume of coffee cups or plastic bags in the waste stream can be tackled by joining existing programs in Australia, such as Simply Cups for collecting and recycling coffee cups and REDcycle for collecting and recycling the soft plastic bags from the waste stream.

5.7. Developing a National Level Model

The results of this study can provide a degree of guidance at the national level, with some results relevant for similar public facilities in Australia. This study found that the most recyclable or compostable materials in the general waste bins at these public facilities were:

1. Organic food
2. Paper towels
3. Plastic bags
4. Coffee cups

The strategies outlined here could remove these items from the general waste stream.

Table 14: Waste Management Plan for libraries and aquatic centers at Blacktown City

Issue	Action	Policy type	% in the waste stream	Total weight of material (Kg/y)	Required minimum infrastructure to complete	Description
High amounts of paper products in garbage stream in aquatic centers	Install signage to use recycling bins higher	Waste reduction	19%	405	_	_
Some general recyclable/recoverable material in garbage stream in both types of centers	Install signage to use recycling bins	Waste reduction	17%	558	_	_
Very high occurrence of food waste in garbage	Worm farm access	Waste reduction	25%	839	Worm farm access	Worm farm would be managed by staff onsite after training
High volume of coffee cups in the waste stream	Join with Simply Cups initiative and create a collection point for them	Waste recycling	6%	214	Separate bins for coffee cups	_
High volume of soft plastic bags in the waste stream	Join with REDcycle program and create a collection point for them	Waste recycling	7%	220	Separate bins for plastic bags	_

6. Summary

In line with designing a carbon reduction toolkit for the Blacktown City Council, the purpose of this part of the research project was to measure proportions of waste categories in public facilities, identify potential opportunities for general waste reduction, and quantify the possible GHG emissions reduction through each opportunity. For this purpose, the study selected two public facilities owned by Blacktown City Council: Max Webber Library and Blacktown Aquatic Centre. Both are large examples of their kind and can represent similar facilities.

Waste audits were conducted at these two facilities, and the different categories of waste were separated and measured. The results showed that only 35% (769 kg/y) of the waste in Blacktown Aquatic Centre and 25% (278 kg/y) at Max Webber Library was general waste. The remainder was either recyclable or compostable. The proposed scenarios for reducing the general waste stream at these two centers and reducing the associated GHG emissions are as follows:

- Removing coffee cups from the general waste stream by introducing small coffee cup bins and collaborating with the Simply Cups initiative in Australia. This would offer a potential GHG emission reduction of 0.275 tCO_2e/y for 10 similar public facilities at Blacktown City.
- Removing plastic bags from the general waste stream by introducing plastic bag bins and joining the REDCycle program, which would offer the potential waste reduction of 1.10 ton/y for 10 similar public facilities at Blacktown City.
- Removing food from the waste stream by providing access to on-site worm farms in each center, offering the potential GHG emission reduction of 0.161 ton/y and potential waste reduction of 839 kg/y.

This research study can be used as the guideline for reducing the general waste from the waste stream in many similar public facilities in Australia at a larger scale. Future studies in this field could concentrate on quantifying the life cycle GHG emissions of three common types of waste in Australia, that is, organic, recyclable, and general waste under different scenarios. These scenarios could include landfilling, commercial composter, common recycling, energy recovery, and incineration.

CHAPTER 7

GHG Emission Reduction by Managing the Urban Land Use

This chapter analyzes strategies for GHG emission reduction by managing urban land use. In particular, it investigates two main strategies for reducing heat islands: tree canopy cover and cool pavement. This chapter compares these two street cooling strategies in terms of their potential for temperature reduction. Finally, this chapter proposes the best combination of cooling street strategies matched to the case study.

1. Introduction

Episodes of extreme heat waves have become more frequent worldwide including in countries that commonly have moderate climates, such as Australia. Sydney is expected to experience an increase in all temperature variables (average, maximum, and minimum) from climate change. The greatest change in maximum temperatures is projected to occur during spring, increasing by up to 2.2°C by 2070 (NSW Government, 2014). In addition, overnight temperature is expected to increase by 2030, which can affect human health. Greater Sydney is expected to have more hot days by 2030, specially in Western areas with additional 5 to 10 hot days. This is because of the great distance of this region from the ocean and thereby the lack of sea breezes, particularly in summer (Office of Environment and Heritage, 2015).

All of these effects are just some sample signs of climate change impacts at the city level, which is commonly known as Urban Heat Islands (UHI). Major cities in Australia are suspected of already experiencing UHI because of rapid urbanization. The further rise of urban temperature would lead to a significant increase in energy demand for cooling.

UHI, which is an urban area with significantly higher temperature than the surrounding rural areas, is the most common phenomena of the 21st century (Hove; et al., 2015) . The higher temperature can be sensed by the human body through hotter surfaces and warmer air (Hove; et al., 2015). These differences are mostly cause by artificial materials used in construction, such as concrete walls, slabs, and roofs, or asphalt pavements. These materials absorb the heat during the day and reflect it at night. Dark surfaces with a low rate of albedo can be the other cause of UHI. These types of surfaces absorb the majority of the heat and do not allow it to reflect in the air. The lack of green canopy in the urban structure is the other reason of heat trapping between blocks in metropolitan cities (V. W. Y. Tam et al., 2018; Zhang, Xie, Gao, & Yang, 2014). While a row of green canopy provides shade for hot surfaces in the summer and reduces the sky view factor, it also maintains the soil moisture and its temperature. All these factors are the causes of UHI in urban climates. Therefore, it becomes necessary to identify and simulate the corresponding cooling strategies to manage each. However, the impact ranges of these UHI sources vary due to regional situations, urban structure, and the local weather. Hence, the street cooling strategies must be justified accordingly. There are no proven street cooling strategies, which can be implemented anywhere in the world. Instead, they must be customized as per the particular conditions of any area.

This chapter identifies the specific microclimate of the Case study, quantifies the effects of different cooling street strategies, compares them, and finally, proposes the best strategy/strategies using the defined criteria to reduce the effects of UHI on the local climate.

2. Previous Studies

Many research studies have examined the causes, impacts, and mitigating measures of UHI effects, mostly from 2001 and after. The first studies in this field focused on analytical methods for assessing the relationship between spatio-temporal factors and UHI effects (Deilami, Kamruzzaman, & Liu, 2018). It can be referred to to Streutker (2010), Tran, Uchihama, Ochi, and Yasuoka (2006) and Weng (2001). Streutker (2010), for instance, used satellite images to determine whether a correlation exists between heat island magnitude and rural temperature. They found that UHI trend is in contrast with rural temperature, while spatial extent was found to be independent (Streutker, 2010).

the newer studies can be categorized based on the methodologies they apply, their sources of data, or their criteria for analysis of UHI effects. Many studies obtained the benefits of satellite data for macroclimate analysis and Google Earth images for microclimate investigation. From them, it can be referred to Yen-Ching Chen, Chiu, Su, Wu, and Cheng (2017), Heinl, Hammerle, Tappeiner, and Leitinger (2015) and Mallick, Rahman, and Singh (2013). For instance, Yen-Ching Chen et al. (2017) use MODIS thermal images and SPOT multispectral remote sensing images over the 1994–2010 period to investigate the effects of urbanization on landscape pattern. Interestingly, they found that urbanization is likely to result in a greater increase in urban heat absorption than in thermal inertia.

Another group of studies focused on identifying the patterns of land cover changes and their impacts on the creation and development of UHI effect. It can be referred to Estoque et al. (2017), Makido, Shandas, Ferwati, and Sailor (2016) and (C. Yang et al., 2017).For instance, Estoque et al. (2017) use Landsat-8 OLI/TIRS data to examine the relationship between land surface temperature (LST) and the changes in land cover in three metropolitan cities of Southern Asia (Estoque et al., 2017).

The other range of methodologies can be classified based on the factors they chose to assess the effects of UHI intensity. These factors can be categorized as the proportion of urban structure, socio-economic factors, which affect the urban texture, urban density, and ecological variables (Lan & Zhan, 2017; Pakarnseree, Chunkao, & Bualert, 2018; D. Xu, Zhou, Wang, Xu, & Yang, 2019). Another important study is that by Lan and Zhan (2017). They investigated the effects of building indicators, including Floor Area Ratio (FAR), Building Density (BD), local Moran's of Building (MB), and Building Height (BH) on the urban thermal environment and found that spatial configuration of building indicators has direct impact on the urban temperature.

Based on the mentioned studies, this research project takes a step forward to categorize the urban texture in the case study, identify the street cooling strategies, and simulate the effects of various strategies on the UHI effect. In the next step, this study undertakes a quantified analysis to compare these different scenarios and proposes the most feasible solution to reduce the microclimate temperature.

Therefore, the main aim of this study is to quantify the effects of different street cooling strategies on the Case study, compare them, and propose the best strategy/strategies to moderate the UHI effect.

3. Materials and Methodology

3.1. Case Study

Figure 41 shows the Urban Heat Islands map of Blacktown city in 2016. The yellow-red areas are regions with surface temperature above the mean. As this figure shows, more than 50% of this city has a surface temperature at least 9.2 °C above the mean. The rest of the region still has a considerable amount of green cover, which moderates the surface temperature by providing daytime shade. In addition, Table 15 summarizes land use changes from 2009 to 2016 in this city. As this table shows, while hard surfaces increased 4.9% during the seven-year period, the tree canopy and shrub cover have gained just 0.4%, and grass cover has decreased up to 5.7%.

Table 15: Land use change of Blacktown City- 2009 versus 2016 (RMIT University, 2016)

Key Statistics	2009	2016	
Tree Canopy Cover	19.2%	19.6%	0.4% Gain
Shrub Cover	4.9%	5.3%	0.4% Gain
Grass Cover	47.6%	41.9%	5.7% Loss
Hard Surface	28.3%	33.2%	4.9% Increase

The selected Case study for microclimate analysis in this research is the Richmond Road from Pop John II Memorial Garden to Kent Street, which covers almost 150 m of the street length in total (Figure 42).

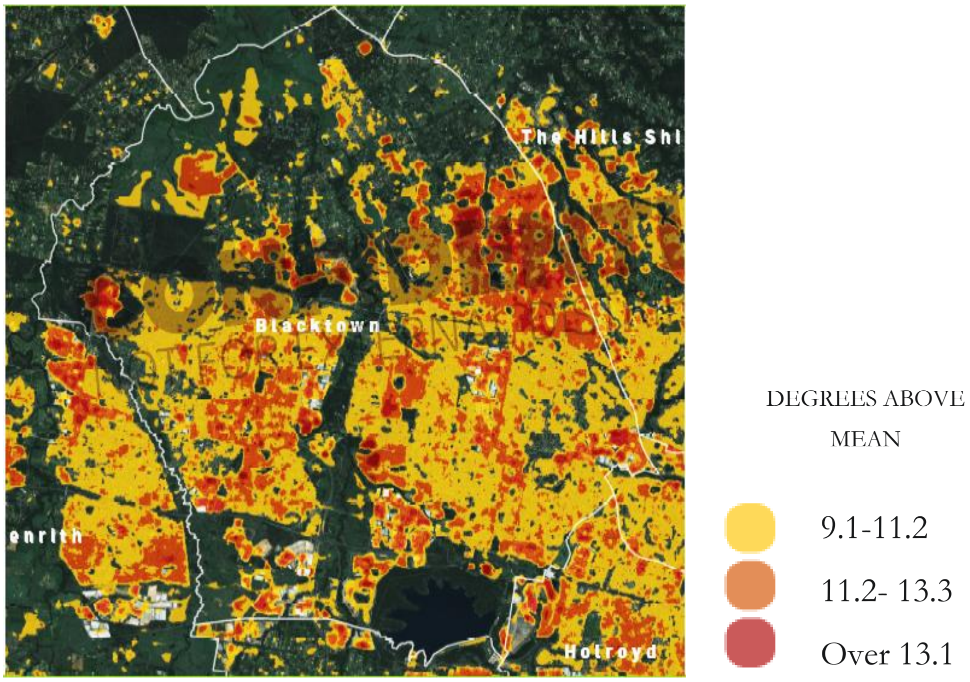


Figure 41: Urban Heat Island Mapping of Blacktown City in 2016 (RMIT University, 2016)

3.2. Urban Texture Simulation

An urban texture can be defined as the geometrical structure formed by the spatial distribution of urban elements such as buildings, roads, and green areas (Ober, Tomasoni, & Cella, 1997). The density and arrangement of these various elements can impact the heat flux to/from the surface to/from the air (Karimipour et al., 2015; Ober et al., 1997). Therefore, the first step in simulating the heat flux from/to the air is identifying the major urban elements and locating them in the simulation model. This study uses ENVI_MET version 4.3.1 for quantifying the microclimate processes and simulating the flows of heat from/to the air. All the different elements of an urban or landscape setting are in interaction with one another in this holistic microclimate software. In addition, this is one of the very few models that analyses the whole parameters in one picture and considers the various climate processes between the elements (ENVI_MET, 2017).

Running an ENVI-met model requires an Area Input File with three-dimensional geometry. In addition, it needs a configuration file summarizing the wind speed and direction, specific humidity, relative humidity, 24-hours temperature data, solar radiation, and initial soil condition of the selected area.

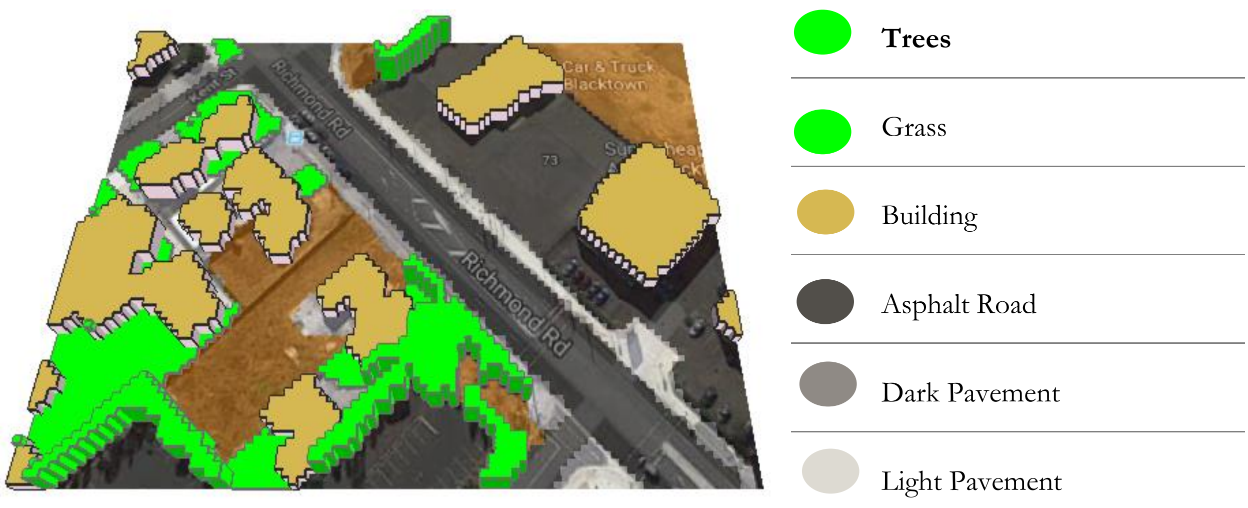


Figure 42: Composition of urban elements in the selected area

Figure 42 illustrates the composition of urban elements in the selected Case study. The elements are trees, grass, building, asphalt road, dark pavement, and light pavement. This is the same categorization for an Area Input File in ENVI-met. The region covers an area of 163m×116m, which is approximately 18900 m². The number of x-Grids and y-Grids is 100 at the length and 80 at the width, respectively. Therefore, the grid size is calculated as follows:

$$Grid\ size\ (m) = \frac{The\ total\ length\ of\ the\ study\ area\ (m)}{The\ number\ of\ grids\ in\ each\ dimension}$$

Therefore, the length of each x-grid cell is equal to 1.63m and each y-grid cell is 1.45m. The total elevation of the model should be equal or more than the double height of the highest feature in the study area (ENVI_MET, 2017). As the highest feature in the area is a 30m tree, the number of z-Grids is 30 with grid size of 2m.

To run the ENVI-met numerical model, it is also necessary to add the local climate data to the model. The model was run on January 1, one of the hottest days in the Sydney summer. The model ran for 24 hours; however, the comparison was in four sample hours at 9am, 3pm, 9pm and 3am. These four hours represent almost all temperature conditions on a summer day at the Case study. Table 16 summarizes the parameters used in the model and their source of data.

Table 16: Climate parameter used in the model

Parameter	Unit	Quantity	Source of data
Wind speed measure in 10 m	m/s	2.8	(WillyWeather, 2018)
Wind direction	Degree	45	(WillyWeather, 2018)
Relative humidity in 2 m	%	69	(Timeanddate, 2018)
Min Humidity	%	50 (3pm)	(Timeanddate, 2018)
Maximum Humidity	%	80 (6am)	(Timeanddate, 2018)
Time step 0	S	10	---
Time step 1	S	5	---
Time step 2	S	2	---
Soil type of the study area	-	Clay-Loam	(NSW Soil and Land Information System, 2018)

For the other required parameters of the model, including solar radiation, clouds, turbulence model, and the Lateral Boundary Condition, the default values of the ENVI-met are kept unchanged.

3.3. Scenario Analysis

To evaluate the street cooling strategies for UHI effects, this study selects and simulates three different scenarios as follows:

- ***Scenario 0:*** Baseline, the current condition of the study area.
- ***Scenario 1:*** Creating a green canopy; planting a row of trees on both sides of the main street.
- ***Scenario 2:*** Cool pavement, which is scenario 1, plus replacing the current dark grey pavement/asphalt parking with light color concrete.

The list of species chosen for street planting and their specifications are in Table 17. As this table shows, the study has chosen three different species with height ranging from 10m up to 30m. The albedo rate of all trees is 0.2 and their CO_2 fixation rate is C3.

Table 17: List of species chosen for street planting and their specifications (Green Spaces, 2018; Pérez-Corona, Vazquez de Aldana, & Heras Paloma, 2013; Thomas, 2016)

Scenario 2: Green canopy				
Selected specious	Height (m)	Albedo	$C0_2$ fixation rate	Root Zone Depth (m)
Acer Negundo	10	0.2	C3	1
Ulmus Minor	20-30	0.2	C3	2
Farxinus Excelsior	12-18	0.2	C3	0.75-2.5

The differences between base scenario and scenario 2- Cool Pavement- has been summarized in Table 18. This table shows that the primary differentiation is in the material selected for the ground surface. Since a large parking at the North-East side of the selected area covers almost 20% of the surface of the region, it provides an opportunity to replace the surface material with a higher albedo surface, such as light concrete. The difference in albedo rate between these two surfaces is 0.6, which can cause a big change in surface temperature.

Table 18: Differences between base scenario and cool pavement scenario

Scenario	**Surface material**	**Albedo**	**Z0 roughness length**	**Emissivity**
Scenario 0: Baseline	Asphalt	0.2	0.01	0.9
Scenario 2: Cool Pavement	Light concrete	0.8	0.01	0.9

3.4. Validation of the Model

Figure 43 shows a comparison between NSW hourly temperature data on January 1, with the ENVI-met simulated data of the same day. This figure shows that the trend of these two series is very close in almost all 24 hours at the correlation rate of 93%. In addition, their peak times follow the same trend. The lowest peak for the NSW data occurred at 6am at 22°C, which is the same lowest peak hour for the simulated data, but at 25°C. Furthermore, the highest peak for the NSW temperature data occurred at 3pm at 35°C versus the maximum temperature for the simulated data, which occurred at 3pm at 34°C. The difference between maximum and minimum temperature for the NSW data is 12°C but for the simulated data is 9°C. (Timeanddate, 2018).

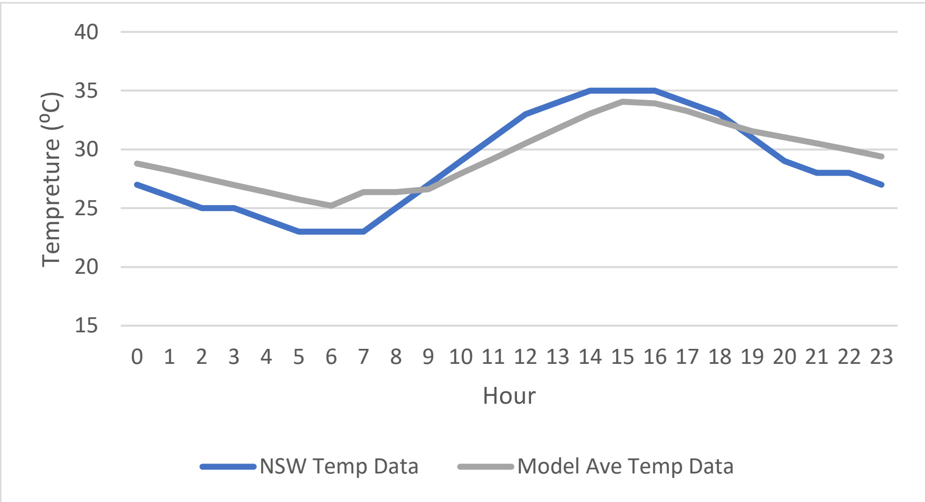


Figure 43: Comparison of NSW temperature date with the ENVI-met simulated temperature for January 1

3.5. Assessment Parameters

The following assessment parameters were used to evaluate the effects of cooling street strategies on the local temperature and being compared with the baseline data . These represent both air and surface temperature and the comfort temperature zone for human health. The selected parameters are as follows: air temperature, surface temperature, sensible heat flux, Sky View Factor (SVF), Mean Radiant Temperature (MRT) and T Air Biomet. The mentioned parameters are as follows:

- ***Surface temperature:*** Surface temperature is the temperature at or near the Earth's surface, which may refer to the air temperature near the ground.
- ***Sensible Heat Flux:*** The turbulent or conductive flux of heat from the Earth's surface to the atmosphere, which is not associated with phase changes of water. A component of the surface energy budget, it is the energy moving from one system to another that changes the temperature rather than changing its phase (Hanania, Stenhouse, & Donev, 2017; Verbruggen, Moomaw, & Nyboer, 2011). Sensible Heat Flux can be calculated as follows:

$$H = R_n - \lambda E - G$$

Where

- *H is the Sensible Heat Flux*
- *Rn is the surface net radiation*
- *λE is the latent heat flux*
- *G is the ground heat flux*

Since Sensible Heat Flux is heat that can be felt by the human body, it is considered as an evaluation factor for this study.

- ***Sky View Factor (SVF):*** A Sky View Factor represents the ratio at a point in space between the visible sky and the hemisphere centered over the analyzed location (Oke, 1982). SVF is a significant factor in UHI analysis, as it can represent the incoming day-time short-wave reflection and night-time long-wave reflection from the earth (Khartwell, 2017). These two parameters are two main factors affecting air and surface temperature.

- ***T Air Biomet:*** Thermal Air BioMet (T Air Biomet) is a factor for calculating Human Thermal Comfort. T Air Biomet essentially summarizes the impact of the four main atmospheric variables, including: Air Temperature, Radiative Temperature, Wind Speed, and Humidity on the human thermal sensation (Bruse, 2014). The temperature used in this model is that formed on the skin (under clothing) after 15–20 min of adaptation to homoeothermic. These parameters are calculated for a 35 year-old man, 1.75m tall, weighing 75kg, and with body surface area of 1.9m² (Fischereit & Schlunzen, 2018).

- ***Mean Radiant Temperature:*** The mean radiant temperature (MRT) is defined as the uniform temperature of an imaginary enclosure in which the radiant heat transfer from the human body is equal to the radiant heat transfer in the actual non-uniform enclosure. MRT is simply the area weighted mean temperature of all the objects surrounding the body (ISO 7726, 1998). MRT equals the mean value of the surrounding surface temperatures, weighted by the respective angle factors, which can be simplified into the following linear form (American Society of Heating Refrigerating and Air-Conditioning Engineers, 2009):

$$MRT = T_1 1F_{P-1} + T_2 1F_{P-2} + \ldots + T_n 1F_{P-n}$$

Where

- *MRT is Mean Radiant Temperature;*
- *Tn is the temperature of surface "n," in Kelvins;*
- *Fp-n is the angle factor between a person and surface "n."*

4. Results and Discussion

4.1. Air Temperature Analysis

The effects of the green canopy scenario and its comparison with the base scenario at 3pm on January 1 have been illustrated in Figure 44. This figure shows the difference in air temperature to be between 0.2°C to 1.3°C based on the location. The most changes in temperature are under the newly planted trees at 1.3°C. The correlation between two diagrams- the air temperature of the cells in the base scenario and the air temperature in the green scenario is 99%. Therefore, the temperature of all cells follows the same trend in both scenarios.

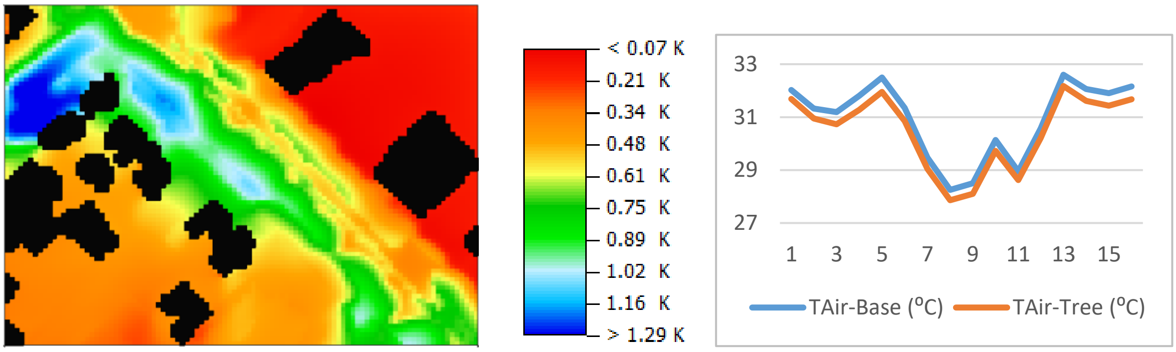


Figure 44: Air temperature differences in Green Canopy scenario versus base scenario- 3pm

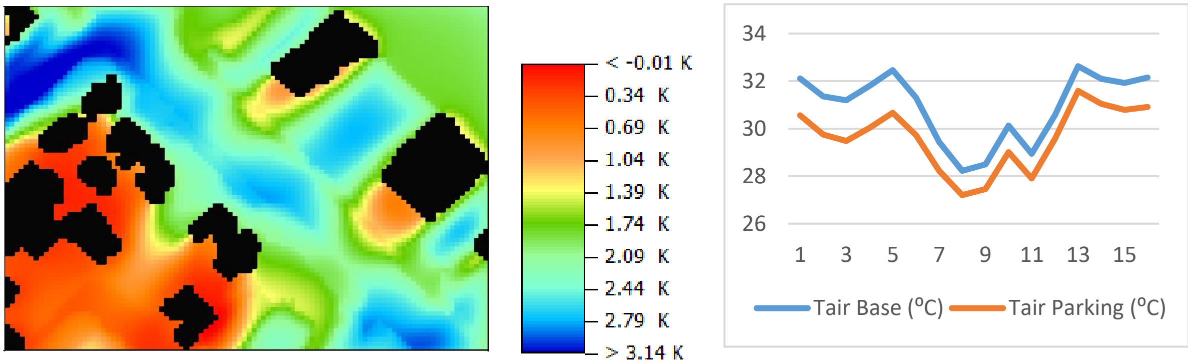


Figure 45: Air temperature difference in cool pavement scenario versus base scenario- 3pm (The number at the x axle represents the random points in the map)

Figure 45 illustrates the air temperature differences in the cool pavement scenario vs. the base scenario at 3pm on January 1. This figure shows the difference in the air temperature in all cells after the effects of the cool pavement scenario. As this figure shows, the maximum difference is observable on asphalt roads where it is affected by the shadow of trees and in parking areas where it is affected by the light-colored pavement. The maximum difference in these areas is about 3.14°C. These new features do not significantly affect the other areas, such as the spaces between homes, the loamy soil, and the grass surfaces. The correlation between the two diagrams- with/ without cool pavement is 99.17%, which shows they are following the same trend. Average air temperature for the base scenario in whole area is 33.4°C, which is 1.6°C higher than the average air temperature in cool pavement scenario, which is 31.8°C.

The air temperature differences between the green canopy scenario and the base scenario at three different times on January 1 have been illustrated in Figure 46. As this figure shows, planting trees alongside the street will reduce the air temperature at day time due to the effects of shadow in the green canopy scenario. However, at night, the difference in the air temperature is mostly negative. Therefore, the night temperature will increase with the presence of trees against the no-trees scenario. This rising trend might be because of the evapotranspiration of trees at night, which creates positive entropy and increases the temperature, although the increase in air temperature is just -0.16°C, which ranges between very low to ignorable.

Another interesting feature in Figure 46 is the changes in air temperature in the cool pavement scenario. As this figure shows, after implementing the cool pavement scenario, both day and night temperatures will decrease considerably. The night temperature decreases around 0.7°C while the day temperature decreases around 3°C. This figure confirms the effect of high albedo surfaces in moderating the air temperature both during the day and at night.

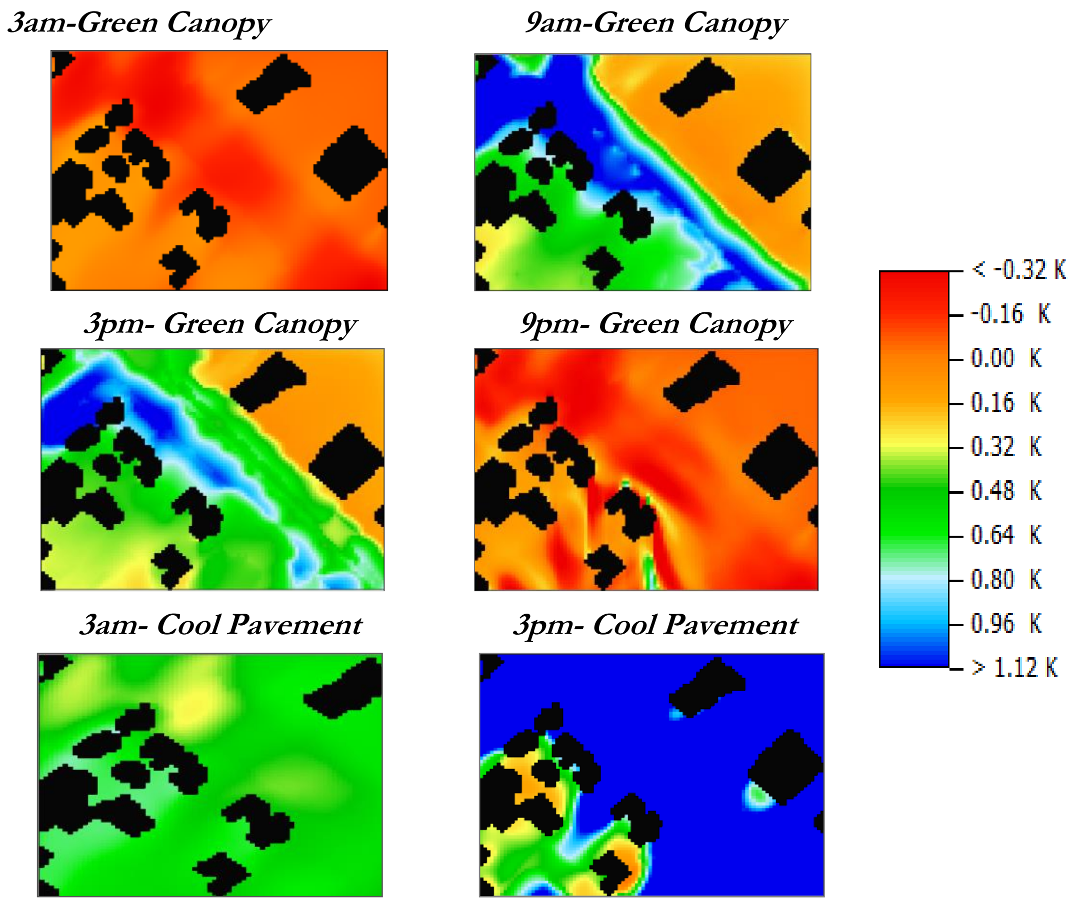


Figure 46: Air temperature differences in green canopy and cool pavement scenarios versus base scenario at different times on January 1

4.2. Surface Temperature Analysis

Figure 47 illustrates the differences in Mean Radiant Temperature (MRT) on the day and night of January 1, in the cool pavement scenario versus the base scenario. As the figure shows, the radiant temperature decreases considerably when affected by the high albedo surface under scenario 2 during the day. In addition, different surfaces react differently to the shade areas and light surfaces. The highest reduction in the Mean Radiant Temperature in the day is seen in asphalt roads with 30°C when it is affected by the shadows under newly planted trees. The average MRT during the day in the base scenario is 61.9°C, versus the average MRT in the cool pavement scenario, which is 39°C. Thus, the average difference in the Mean Radiant Temperature during the day is 22.7°C. This high variance shows the heavy impact of high albedo surfaces and shading on the radiant temperature of various surfaces. However, the difference in radiant temperature at night in the cool pavement scenario is low in comparison to the day variances. The maximum decrease in the radiant temperature at night is at around 3°C, which is mostly at its peak on the asphalt road and the replaced pavement areas. The correlation between the two figures at 3pm is 84% and at 3am is 73%. This close correlation confirms that the different cells follow almost the same trend at various times.

Figure 48 illustrates the difference in surface temperature in both scenarios- green canopy and cool pavement- at 3pm and 3am on January 1. According to Figure 48 (a), planting trees alongside the street reduces the surface temperature of the shading areas by up to 8°C; however, as Figure 48(b) shows, the shadow during the day does not affect the surface temperature at night. There is very low-to-negative difference in surface temperature of the green canopy scenario at night, which is equal to -0.7°C under the shadows.

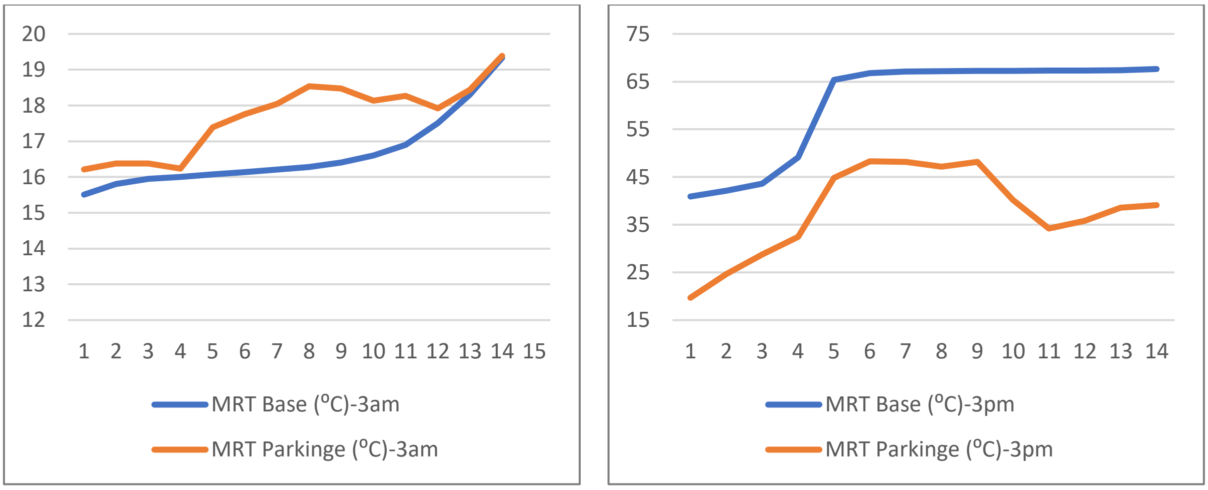


Figure 47: Difference in Mean Radiant Temperature in the cool pavement scenario versus base scenario at 3am/3pm on January 1(The number at the x axle represents the random points in the map)

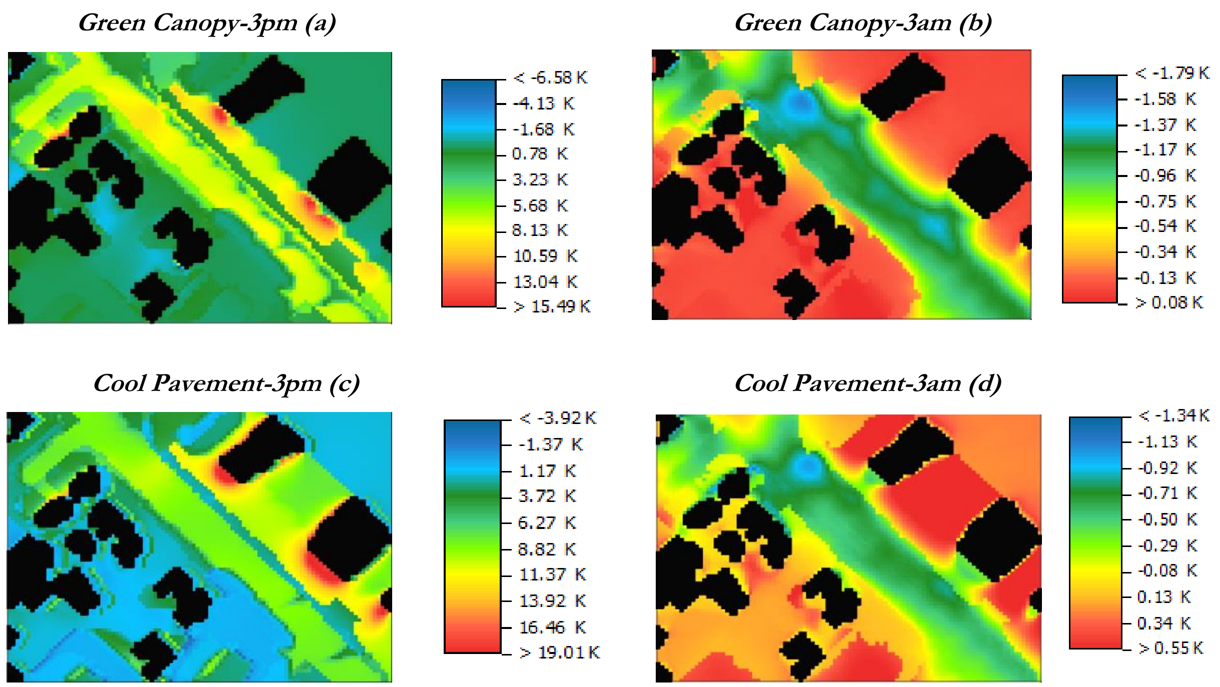


Figure 48: Surface temperature differences in two scenarios of daytime and nighttime on January 1

However, the reduction in surface temperature is higher in the cool pavement scenario. According to Figure 48 (c), the maximum reduction in surface temperature at 3pm in this scenario is equal to 19°C, which is much higher than the amount of reduction in the surface temperature in the green canopy scenario. Another difference between these two scenarios is the decline in surface temperature in the parking area in the cool pavement scenario and the green canopy scenario. As Figure 48 (c), (d) show, the changes in temperature in the parking area is up to 9°C in the cool pavement scenario in contrast to 3°C in the green canopy scenario. However, the difference in the surface temperature of the parking area at night in the cool pavement scenario is very low to ignorable at around 0.55°C.

4.3. Sky View Factor and Thermal Air Biomet Analysis

Figure 49 illustrates the relationship between the Sky View Factor (SVF) and T Air Biomet. As this figure shows, the SVF has direct correlation with T Air Biomet at the rate of 74% at 3pm. Therefore, the T Air Biomet follows nearly the same trend as the SVF. The highest difference in T Air Biomet between the base scenario and the cool pavement scenario occurred at the North East corner of the studied area at around 2.17°C. This is where the

SVF difference is highest rate at around 37%. However, the correlation between T Air Biomet and SVF is negative at 3am at the rate of -70%. It means that the area that has normally the lowest difference in SVF, experiences the highest difference in T Air Biomet at night of around 0.5°C to 0.87°C. The T Air Biomet difference in asphalt road at night is very low to ignorable at around 0.4°C. This might be because of the heat storage capacity of the asphalt road, which retains the heat in the day and releases it during the night.

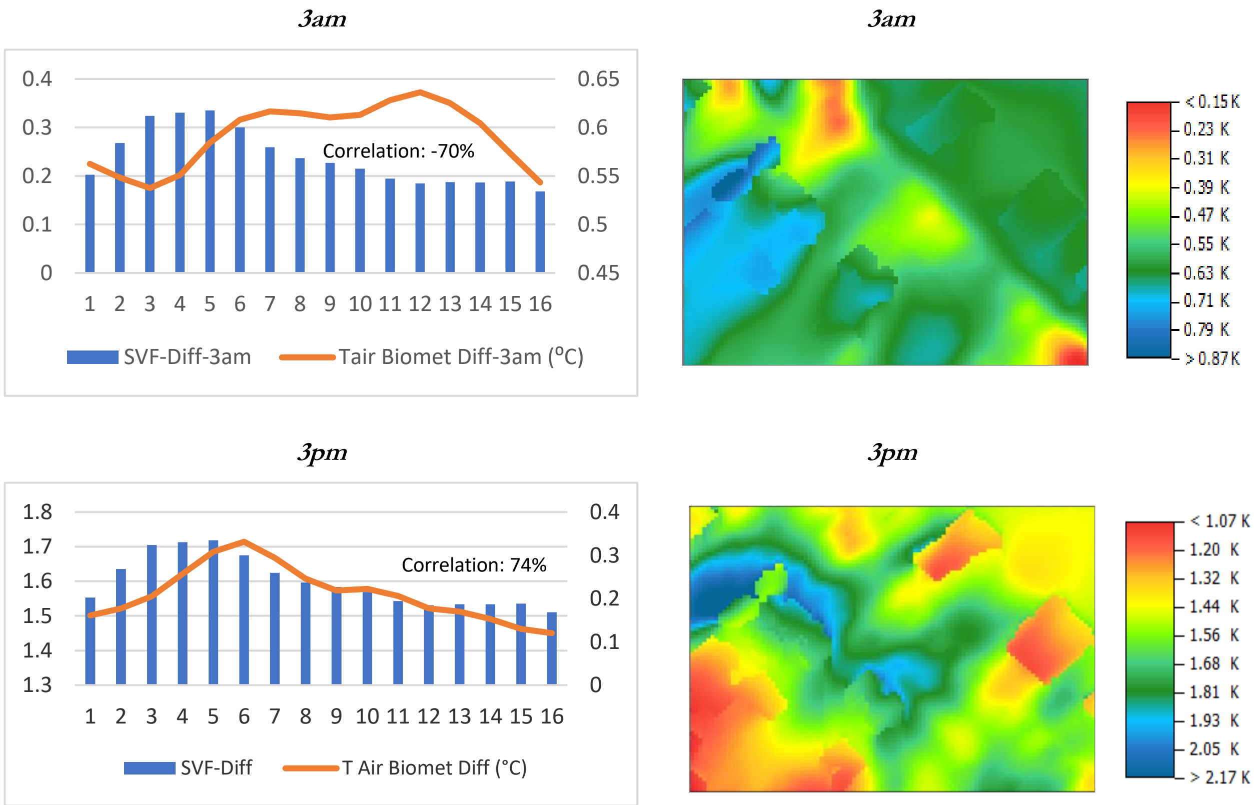


Figure 49: Relationship between Sky View Factor and T Air Biomet in the cool pavement scenario at 3pm and 3am on January 1

4.4. Sensible Heat Flux Analysis

Figure 50 illustrates the relationship between the differences in SVF and the differences in Sensible Heat Flux after implementing both scenarios. According to this figure, the changes in Sensible Heat Flux have an indirect relationship with the changes in SVF at the rate of -94%. Therefore, where the changes in SVF are higher natively, the changes in Sensible Heat Flux will be higher positively. The changes in SVF are higher in the street in the middle of the studied area. This region used to have a very high view rate of the sky; however, after planting trees, its SVF has reduced considerably, at the rate of -0.33%. When the trees block out the sun, the Sensible Heat Flux reduces by more than 380 W/m². The North-East part of the studied area also shows high reduction in Sensible Heat Flux, where asphalt parking was replaced with light concrete parking. The changes in Sensible Heat Flux in this part of the region are also too high, at over -380 W/m². Therefore, the conductive heat flux from the Earth's surface to the atmosphere is meaningfully negative compared to the base situation.

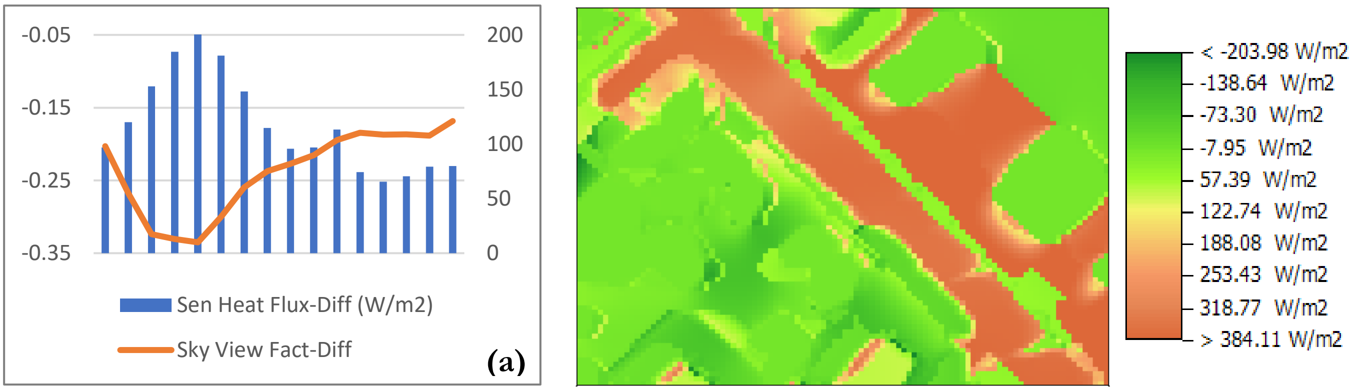


Figure 50: Difference in Sensible Heat Flux in the cool pavement scenario versus base scenario and its relationship with the Sky View Factor

4.5. Different Surfaces Reaction Analysis

Figure 51 illustrates the reaction of different surfaces of the studied area to shadow, which reflects in their surface temperature. As this figure shows, different surfaces react differently to the sun and shadow. The most direct relationship between shadow flag and the difference in the surface temperature is at the asphalt surface. According to this figure, with the first signs of the sun in the morning, the difference in surface temperature of the asphalt road increases gradually to reach its highest difference at 12pm at +6°C. In contrast, the surface temperature difference declines steeply after the first signs of shadow at 7pm and reaches its lowest point at +1°C at around 6am.

The reaction of light and dark concrete to the sun and shadow are almost in contrast. The main difference is that the changes in temperature are positive in dark concrete but negative in light concrete. This means that the light concrete pavement is colder than the reference surface up to 8°C at 2pm in contrast to the dark concrete surface, which is warmer, on average, than the reference surface up to +2.5°C at 11am. The changes in night temperatures have a fixed rate at around 1.5°C in dark pavement and 1°C in light concrete.

The temperature difference in grass-covered surfaces has indirect correlation with the sun and shadow at the correlation rate of -80%. From 8am to 2pm the temperature difference is between +0.5°C to 2°C; however, after 2pm to 7am of the next day, the changes in temperature vary between -2°C to -8°C..

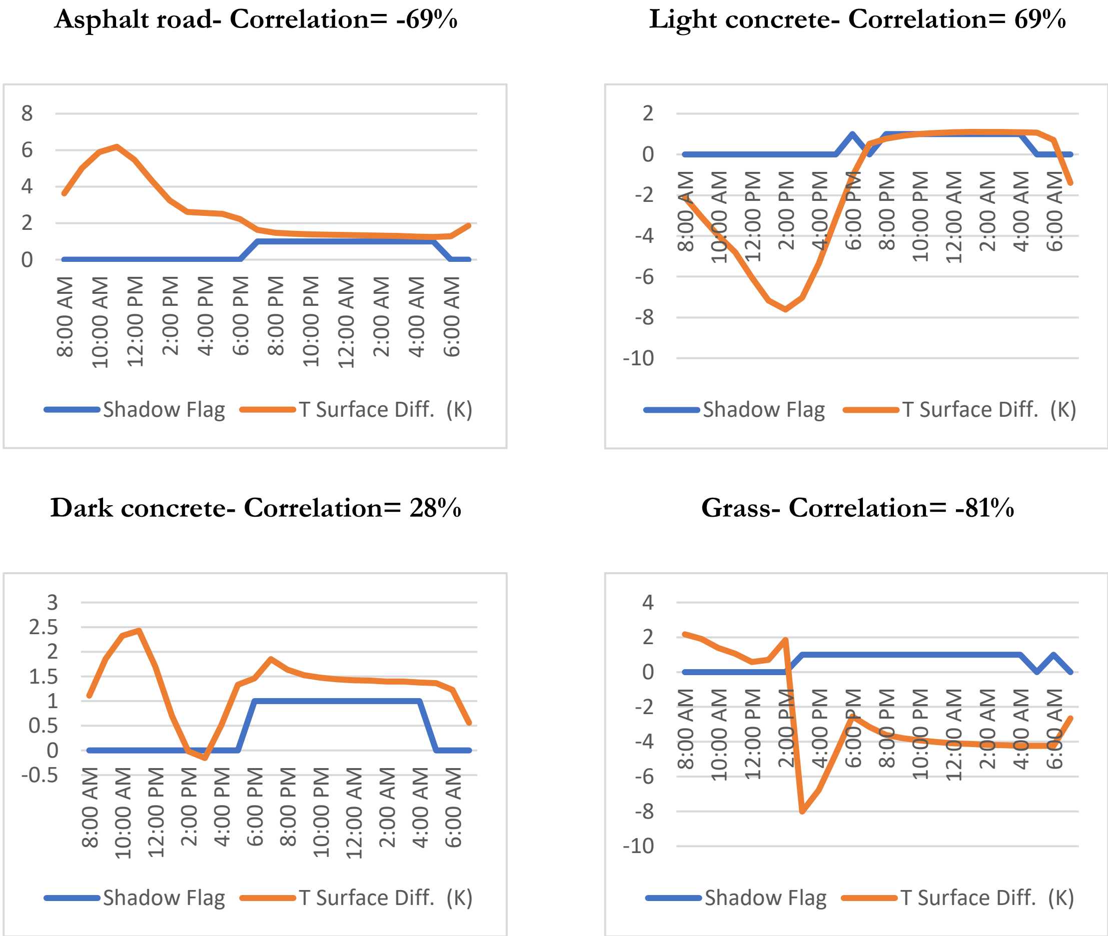


Figure 51: Reaction in temperature of different surfaces of the studied region to shadow

5. Summary

The aim of this chapter was to compare the differences of street cooling strategies at one of the largest suburbs of Sydney metropolitan, analyze them, and propose the best set of UHI mitigation scenario. Considering that any particular region has its own microclimate processes, including wind speed, sun and shadow hours, natural green cover, the average building height and …, a unique suggestion that is suitable for any region cannot be applied and it is necessary to propose a customized set of UHI mitigation strategies. Using the ENVI-met microclimate processor, this study combined all various microclimate variables together considering the specific climate of the studied zone to reach a suitable strategy for cooling down the sensible temperature at street level.

Figure 52 summarizes the proposed list of street cooling strategies for the selected pilot. As this figure shows, since the direction of the prevalent wind in the study area is North-East to South-West, if the temperature of the North-East part of the region can be decreased, the South-West will become colder automatically. Therefore, no more expensive strategies are necessary for the South-West if we reduce the temperature in the North-East.

Figure 52: Summary of suggested street cooling strategies for the Case study

The list of final proposed cooling strategies is as follows:

- Replacing the loamy soil with grass at the North-East corner of the studied region. This is because according to Figure 51, the surface temperature of grass is not very sensitive to the sun and shade cycle. Thus, even without sufficient shade, the surface temperature will be low.
- Replacing the asphalt parking areas at the North-East and South-East sides of the region with light concrete pavement with higher albedo rate to keep the surface temperature up to 20°C lower than its normal temperature.
- Planting tall trees and the North-East side of the street to provide shade during the day for the whole length of the street. It will reduce the air temperature by up to 3°C and the surface temperature by up to 11°C in the afternoon of a hot summer day.
- Planting short trees at the South-West side of the street to provide shadow for the southern pavement. This will reduce the sensible heat flux up to 382 W/m^2 for those traveling along the street.
- Furthermore, the green canopy strategy mostly reduces the daytime temperature;

however, the cool pavement scenario reduces both daytime and nighttime temperatures.

Applying all these street cooling strategies, we can reduce the air temperature at the hottest time of a summer day by up to 3°C, surface temperature by up to 20°C, mean radiant temperature by up to 30°C and the sensible heat flux by up to 382 W/m^2.

Future studies in this field can focus on the effects of the micro urban elements on the UHI effect. In particular, they can investigate the amount of energy consumption in buildings and their impact on the surrounding microclimate. If the effect of energy consumption in buildings on the sensible temperature can be quantified, the relevant cooling strategies and their sensitivity on reducing the temperature can be simulated. This will then assist in reducing the UHI effects in the urban environment.

CHAPTER 8

GHG emission Reduction by Increasing Energy Efficiency

SUMMARY

This chapter analyzes the strategies for GHG emission reduction by lowering the energy consumption. It introduces the energy efficiency initiatives undertaken by the Council from 2008 to 2016 and compare them in terms of energy efficiency, payback period, and total required capital. Finally, it introduces a combination of energy reduction strategies to be matched to the Council's assets.

1. Introduction

Under the Paris Agreement, Australia has committed to reduce emissions by 26–28% below 2005 levels by 2030 (Australian Government, 2016). To reach its committed reduction level by 26–28% below 2005 by 2030, all states and their subsidiary cities have started developing mitigation policies and action plans highlighting the measures necessary, the time frame of each measure, its allocated budget, the estimated level of GHG reduction, and the forecasted payback time.

In accordance with this trend, this chapter aimed to introduce and analyze the measures undertaken by Blacktown City Council in reducing the GHG emission from its assets. Particularly, this chapter examined the measures for reducing the energy consumption of the Council's buildings and the other assets, such as pools and open spaces parks.

Since introducing any new measure for reducing the energy consumption in the buildings was beyond the scope of this research, this study did not introduce any novel green initiative. Instead, it undertook a comprehensive analysis of the measures already undertaken and completed by the Council and compared them. This study took the following steps to compare and analyze the Council's green initiatives:

1. Preparing a list of the Council's completed measures for reducing the energy consumption of its assets
2. Estimating the total GHG emission reduction for each measure
3. Extracting the real cost associated with each measure from the Council's database
4. Extracting the initial and annual cost associated with each measure
5. Extracting the payback period of each measure, considering its initial cost
6. Extracting the life time of each measure and comparing all measures

The period of the study is from 2011 to 2016 and all the data gathered are from the audit reports of the Council database.

2. Previous Studies

Many studies investigated various strategies to reduce energy consumption in the buildings, which can be categorized in several groups.

One group of studies has focused on strategies for effective reduction of building energy consumption. These studies provide enhanced supervision strategies for reduction of building energy consumption. One can refer to (Caputo, Costa, & Ferrari, 2013; Hu, Weir, & Wu, 2012; Ru et al., 2010; W. Y. V. Tam, Le, Tran, & Wang, 2018; J. Yao & Zhu, 2011). For example, J. Yao and Zhu (2011) investigated the reasons behind the growing rate of energy usage in buildings. They found that enhanced government supervision strategies, strict control, integrating information and frequently monitoring energy consumption in large-scale public buildings can help observing and reducing energy usage in buildings. Moreover, a carrot-and-stick approach with expert checklists for the application of renewable energy, is another strategy with great advantage in mitigating the energy consumption of buildings (Caputo et al., 2013).

The other group of studies concentrates on a building's lifecycle energy consumption. One can refer to (Al-Ghamdi, A.M.ASCE1, & Bilec, 2017; Herrmann & Moltesen, 2015; T. Ramesh, Ravi Prakash, & K. K. Shukla, 2010; W. Y. V. Tam et al., 2018). For instance, T. Ramesh et al. (2010) showed that operating energy by 80-90% and embodied energy by 10-20% of a building energy usage are significant factors to a building's lifecycle energy demand. It is possible to considerably reduce a building's lifecycle energy demand by mitigating its operating energy through passive and active technologies. Although using these technologies, is be resulted in a slight increase in embodied energy, in general an excessive use of passive and active features in a building may be counterproductive (T Ramesh, Ravi Prakash, & K.K Shukla, 2010).

Another group of studies investigated the factors affecting the energy efficiency of a building. One can refer to (Biantoro, 2018; Egwunatum, Joseph-Akwara, & Akaigwe, 2016; Habib, Hasanuzzaman, Hosenuzzaman, Salman, & Mehadi, 2016; Kong, Lu, & Wu, 2012). For instance, Habib et al. (2016) conducted an energy audit at Garments in Bangladesh to identify energy using equipment and energy consumption breakdown. They identified various energy saving technics and their impacts on GHG emission reduction. From them they have listed variable speed drive (VSD) and high efficiency motors (HEM) as the two highly efficient strategies for reducing electricity bills and GHG emissions

3. Materials and Methods

3.1. Blacktown City Council Emission Breakdown

The Council, in 2010, calculated its ecological footprint for 2008-2009 as being 1,802 hectares. Approximately 20% of the Council's total ecological footprint is created by consuming electricity for buildings and street lighting (Blacktown City Council, 2015a). An overview of the Council's greenhouse gas emissions from 2005 to the present is presented in Figure 53.

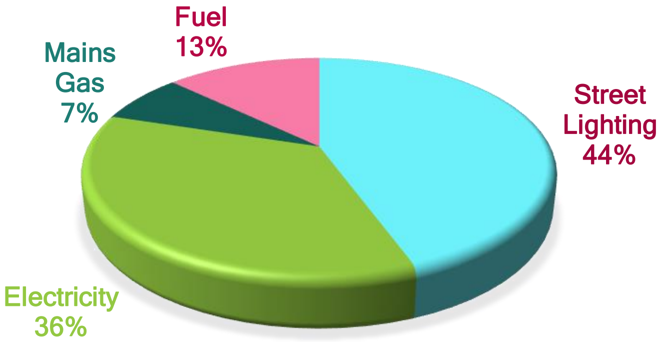


Figure 53: Blacktown City Council GHG emissions by source-2005 to present

By the end of 2016, Blacktown City's population was 340,000. By 2036, Blacktown City will be home to almost 497,000, with 42.16% growth (id the population experts, 2016). This means the city anticipates an average annual growth rate of approximately 2.1%. This growth in the community will create an increased demand for Council services and a corresponding increase in greenhouse gas emissions. Population growth presents both opportunities and threats for the Council to serve the growing needs of the population and to challenge the emerging policy requirements to reduce GHG emission.

3.2. Energy Audit Process

The evaluation process of energy consumption before and after implementation of green initiative measures undertaken by the Council is the energy audit process. It is the process of reviewing energy use of each asset against similar buildings, identifying energy saving opportunities, and cost-energy analysis. For the energy audit process, the Council allocates an auditor to each building/ asset, who leads the entire process. Depending on the facility or asset, the Council also contributes financial or branding staff in the procedure.

The energy audit process by the Council is in the following phases (Laboratory, 2011):

- Preliminary review of energy use: Facility benchmarked against similar buildings; Base energy load identified
- Site assessment: Site data collected, immediate energy saving opportunities identified
- Energy and cost analysis: Saving energy estimated
- Completion of audit report: Action plan developed for next steps

However, the audit process requires some pre-process considerations. One important part of these considerations is determining the assessment method, as there are many assessment methods available. According to the type of Australian building and the climate status, two international energy assessment methods can be selected for the audit process. These are the American Society of Heating, Refrigeration, and Air Conditioning Engineers (ASHRAE) Level II, III and International Performance Measurement + Verification Protocol (IPMVP) Options A, B, C, which cover the requirements of the audit process, benefit from useful toolkits, and well-written instructions.. The measures associated with heating, ventilation, air conditioning, and refrigeration can be assessed by the ASHRAE and the utilization of electricity, such as retrofit lighting, solar panel systems, and carbon-offset program can be evaluated by the IPMVP. A summary of the two different systems and the evaluation procedure is as follows.

3.2.1. ASHRAE Level II, III

The purpose of this standard is to provide minimum requirements for the siting, design, and construction, and plan for operation of high-performance green buildings. This is to (a) balance environmental responsibility, resource efficiency, occupant comfort and well-being, and community sensitivity; and (b) support the goal of development that meets the needs of the present without compromising the ability of future generations to meet their needs (American Society of Heating, 2016). The standard presents provisions in six major categories:

- Site sustainability
- Water use efficiency
- Energy efficiency
- Indoor environmental quality
- Impact on the atmosphere, materials, and resources
- Construction and plans for operation

The scope of the standard includes new buildings and their systems, new portions of buildings and their systems, and new systems and equipment in existing buildings. This study has used the energy efficiency scope of this standard for new systems and equipment in existing buildings to estimate the amount of energy use before and after implementation of each green initiative; this methodology is the Life-Cycle Energy analysis (American Society of Heating, 2016; TRANE, 2017).

The life cycle energy approach, analyses all energy inputs to a building from the construction phase to demolition. The construction phase includes manufacturing and transportation of building materials along with any other forms of energy usage for the installation of building or for the erection and renovation of buildings. The operation phase includes all activities related to the use of buildings, over their life spans. They range from maintaining comfort inside the buildings, water use, and powering appliances. Finally, the demolition phase includes the destruction of the building and transportation of dismantled materials to landfill sites and/or recycling plants (T Ramesh et al., 2010). Considering the aims of this research, which is the analysis of the Council's measures for existing properties; this study only observes the operation phase.

Operating energy, calculated in this study is the energy required for keeping comfortable conditions and daily function of the building. It is the required energy for heating, ventilation, air-conditioning, hot water, lighting, and for running appliances.

The formula for calculating the operating energy is shown in Equation 8.

$$OE = E_{OA} \times L_B$$

Equation 8

Where

- *OE = operating energy in the life span of the building before or after implementing the green initiative;*
- *EOA = annual operating energy;*
- *LB = life span of the building (T Ramesh et al., 2010)*

3.2.2. IPMVP Options A, B, C

The International Performance Measurement and Verification Protocol (IPMVP) options A, B, C, and D has been a reference for calculating energy and demand savings in this research for retrofit lighting, solar panel systems, and carbon offset programs. IPMVP is a guidance document describing common practices in measuring, computing, and reporting savings achieved by energy or water efficiency projects at end user facilities. The IPMVP presents a framework and four measurement and verification (M&V) options for transparently, reliably, and consistently, reporting the savings of a project. M&V activities include site surveys, metering energy or water flow(s), monitoring independent variable(s), calculation, and reporting (EVO, 2012).

It is not possible to quantify energy savings directly, since these savings are the absence of a used or demand for energy/ water. Instead savings are measured by comparing a previous energy use or demand and comparing it with after implementation of a program, making suitable adjustments or an efficient initiative. It is necessary to segregate the energy effects of a savings program from the effects of other simultaneous changes affecting the energy using systems. The comparison of before and after energy use or demand should be made consistently, using the following general Equation 9 (EVO, 2012):

$$Saving = (Baseline - Period\ Use\ or\ Demand - Reporting - Period\ use\ or\ Demand) \pm Adjustment$$

Equation 9

To calculate the energy savings of the measures by Blacktown City Council, the following three options of IPMVP have been used based on the situation and the availability of data, which are abstractly introduced below:

Option A: Installation verification and its calculation

Under Option A, installation verification can be used for the Council's GHG reduction measures. Key Parameter Measurement, energy quantities can be derived from a computation using a combination of measurements of some parameters and estimates of others. All the estimates of this study in this option are based on historical data, such as recorded operating hours from the baseline, equipment manufacturers' published ratings, laboratory tests, or typical weather data.

Baseline or reporting-period energy measurements involve measurement of only one parameter under Option A, and estimation of the other. To calculate the actions under option A, the amount of savings is simplified as Equation 10 (EVO, 2012).

$$\begin{aligned} Option\ A\ Saving \\ &= Estimated\ Value\ \times (Baseline\ Period, Measured\ Parameter \\ &- Reporting\ Period, Measured\ Parameter) \end{aligned}$$

Equation 10

Option B: Retrofit isolation and its calculation

Under Option B, retrofit isolation can be estimated for the Council's measures. In this option, all Parameter Measurement requires the measurement of all energy quantities. Option B methods was generally more difficult and costly than those of Option A. However, these options have produced more certain results when load and/or savings patterns were variable. Under Option B, there was no need for adjustments, routine or non-routine, depending upon the location of the measurement boundary, the length of the reporting period, or the amount of time between baselines and reporting period measurements. The formula used for Option B is expressed as Equation 11 (EVO, 2012).

$$Saving = Baseline\ Energy - Reporting\ Period\ Energy$$

Equation 11

Option C: Whole facility and its calculation

This Option involves the use of utility meters, whole-facility meters, or sub-meters to assess the energy performance of an entire facility. The measurement boundary encompasses either the whole facility or a major section. This Option determines the collective savings of the facility monitored by the energy meter. In addition, the whole-facility meters were used, the savings reported under Option C included the positive or negative effects of any changes made in the facility (EVO, 2012).

Energy data for Option C are derived from utility meters, either through direct reading of the meter, or from utility invoices. Utility bills sometimes contained estimated data, especially for small accounts. Sometimes it is not possible to determine from the bill itself whether the data is from an estimate or an actual meter reading (Braun, Altan, & Beck, 2014).

3.3. GHG Emission Calculation

This study has used the National Greenhouse Accounts (NGA) of Australia for estimating GHG emissions before and after implementation of each measure. The NGA Factors have been prepared by the Department of the Environment and are designed for use by companies and individuals to estimate GHG emissions.

For calculating the GHG emission from electricity use, before and after the execution of each measure, the "indirect emission from electricity" method was used (Australian Government, 2015). The factors estimate emissions of CO2, CH4, and N2O expressed together as carbon dioxide equivalent (CO2e). The greenhouse gas emissions in tons of CO2e attributable to the quantity of electricity used are calculated using Equation 12 (Australian Government, 2015):

$$Y = Q \times \frac{EF}{1000}$$

Equation 12

Where

- *Y is the emissions measured in CO2e tons.*
- *Q is the quantity of electricity purchased (kilowatt hours).*
- *Q is the quantity of electricity losses for that transmission network or distribution network during the year.*
- *EF is the emission factor for New South Wales (kg CO2e per kilowatt hour) (T Ramesh et al., 2010).*

3.4. Boundary of this Research and Summary of Methodologies

This chapter summarizes the approach of the Council's energy consumption audits and its GHG emission calculation, which is illustrated in Figure 54. As this figure shows, among all the phases of the Life Cycle Energy Analysis, this study only examines the Operation phase. This is because of the nature of the research, which was to compare the Council's measures towards GHG emission reduction of its existing assets, and not new ones. Therefore, practically, the two other phases were not considered and the analysis was focused on the use phase.

The second phase of the study has been the Energy Auditing Process. In this phase, all the opportunities for mitigating the energy use have been distinguished according to an audit process. These introduced measures can be categorized in improving the HVAC system, hot water supply, powering appliance, retrofit lighting, and solar power installation, which encompass most of the opportunities for mitigating energy consumption in any kind of building.

In phase three, which is estimation, the energy consumption of the asset before and after execution of each action was estimated. For this estimation, the two international systems ASHRAE Level II, III and IPMVP Options A, B, and C will be introduced. In accordance to these systems, the amount of energy saving and the life span of each action can be estimated.

In the final phase, this study calculated the GHG emission for each measure before and after implementation of any green initiatives. In addition, it calculated the cost of outlaying, the payback period, and cumulative GHG reduction.

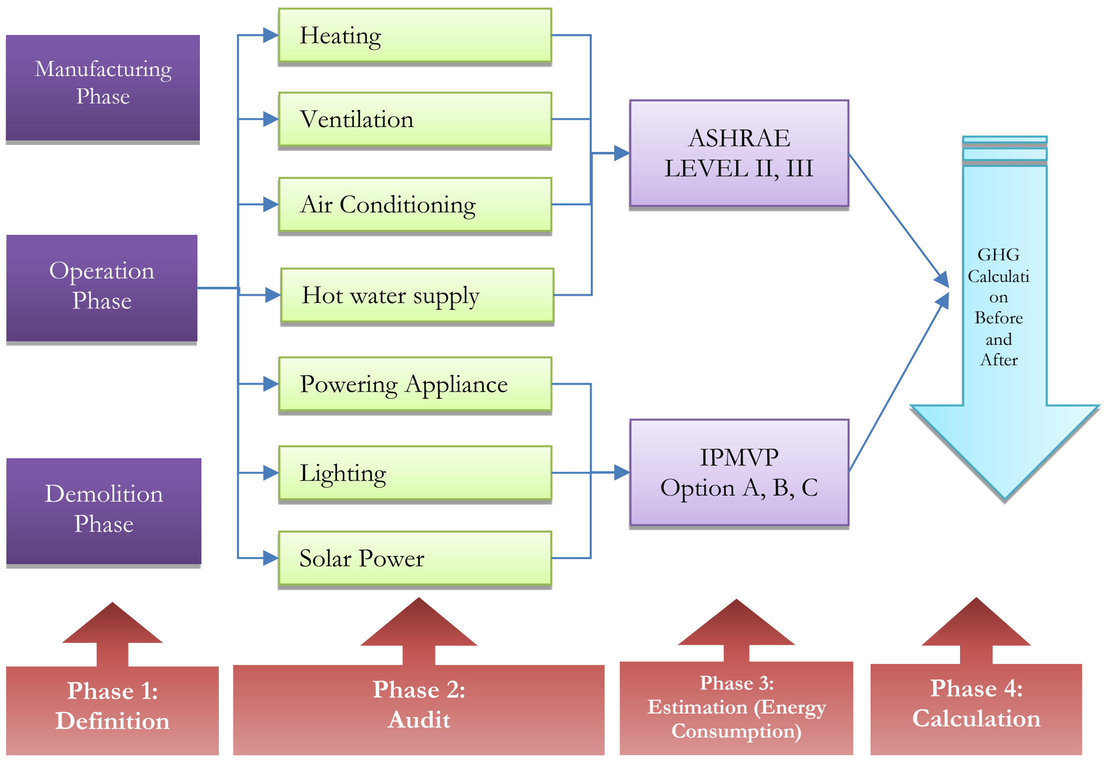


Figure 54: Summary of methodologies in this case study

4. Results and Discussion

4.1. Council's Emissions in 2012-2016

Table 19 shows the Council's GHG emissions during 2012-2016. Figure 55 also illustrates the trend of GHG emission and the amount of emission reduction per year during the same period. As this figure shows, the Council's emission has increased from 41030 tonnes in 2012 to 46179 tonnes in 2016. Therefore, the average increase in the Council's emission was 11.15% during this period. Simultaneously, the Council has taken measures against climate change, so that the amount of GHG reduction has increased from 2814 tons in 2012 to 10547 tons in 2016. Thus, the average growth in GHG reduction has been 374%, which is much higher than the level of GHG increase in the same time. By deducting the amount of total GHG emission per year by the total GHG reduction as the result of the Council's abatement measures, it can be concluded that the gross GHG emission after affected by the Council's measures has decreased during the study period. In other words, despite the rising trend in the Council's emissions, there is a decrease in the level of total emission from 38216 tons in 2012 to 35632 tons in 2016. Therefore, the average decrease in GHG emissions in the city Council after the Council's measures has been 6.76% in total, or 1.35% per year.

Table 19: Estimation of Blacktown city Council's GHG emission in 2012-2016

Year	Council gross emission (Tonne)	Council's emission reduction (tonne)	Council emissions after reduction by the measures
2012	*41030*	*2814*	*38216*
2013	*42261*	*4720*	*37541*
2014	*43529*	*6872*	*36657*
2015	*44835*	*7458*	*37377*
2016	*46179*	*10547*	*35632*

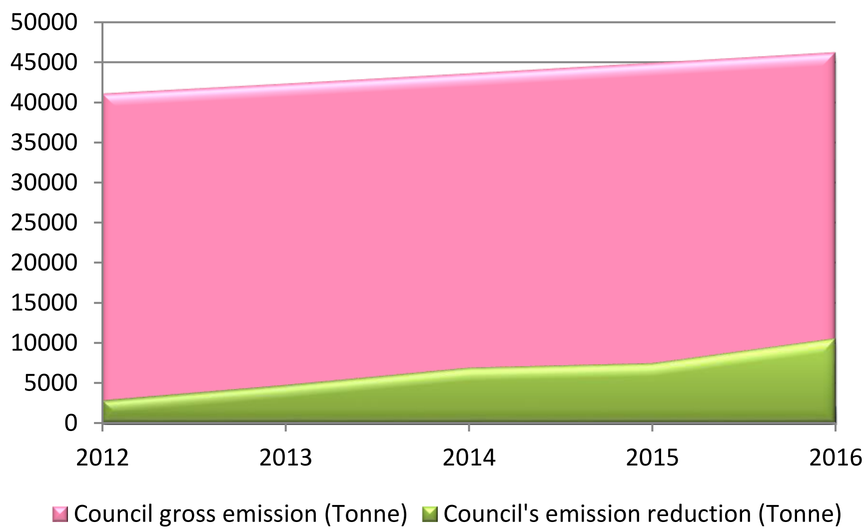


Figure 55: Blacktown City Council's emission and GHG reduction for 2011-2016

4.2. Council's Measures towards Emission Reduction

Blacktown City Council started combating climate change from 2008, with some practical actions, and developed its first policy and action plan in 2011. By the end of 2016, the Council has taken 32 measures to reduce GHG emissions, the highlights of which are in Table 20.

As shown in Table 20, some measures have contributed more in reducing emissions based on their size and technical attributions. One of the main critiria for comparing the measures and prioritizing them is simply their cost. The cost associated with each of the Council's measures and their comparison is in **Error! Reference source not found.**.

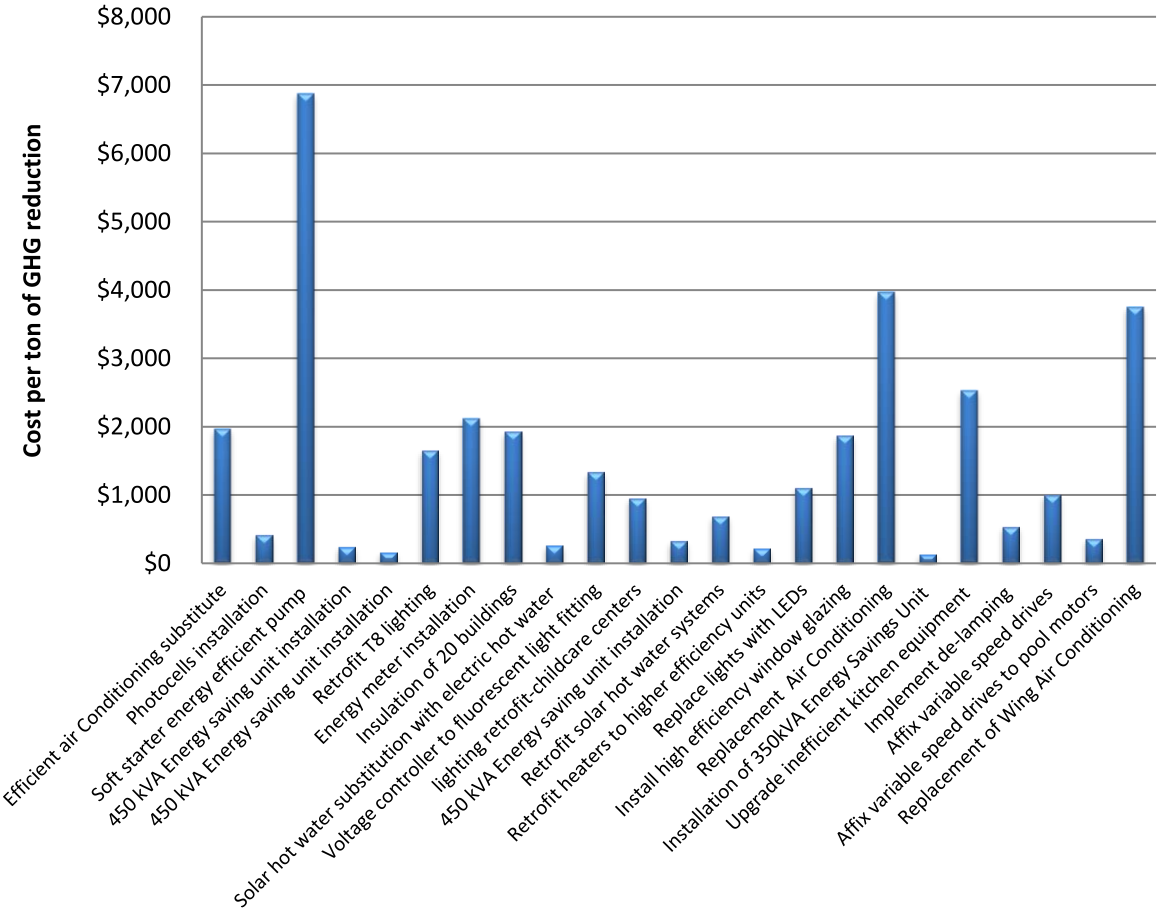


Figure 56: Cost per tonne of GHG reduction per measure in Blacktown City Council (Blacktown City Council, 2015b)

Table 20: Blacktown City Council's actions against climate change from 2008 to 2016 (Blacktown City Council, 2015b)

Initiative	Year/s of implementation	Greenhouse Gas Reduction Outcome (in tons)
Implement energy and water efficiency measures at the Council's highest consumption sites	2008 - 2010	1147 tons per annum
Installation of 50kW solar power system at the Council	2011-	70 tons per annum
Installation of solar panels at other Council facilities	2005 – 2014	13.8 tons per annum
Utilize renewable fuels (10% Ethanol in leaseback fleet, 20% Biodiesel in Heavy Vehicle Fleet)	2006 – 2015	10 tons annually
Divert Blacktown City's residential waste collection to an Alternative Waste Treatment Facility to be composted and the methane generated used to produce renewable energy to power the facility	2005 - 2015	Approximately 9000 tons per annum (variable)
Purchase of Green Power	2006 - 2010	1,033 tons per annum
Regenesis carbon offset program – planting native carbon forests to offset carbon emissions	2009 - 2010	3,657 tons over a 40-year period
Blacktown Solar City partnership program providing energy efficiency and solar power systems for local residents and businesses	2007 - 2011	17,500 tons total cumulative
Provide environmental education to the community on climate change mitigation and sustainable living	2006-2015	Not directly quantifiable – indirect benefit
Development of a Sustainable Events Policy	2011-2015	Not directly quantifiable – indirect benefit
Development of a draft Environmentally Sustainable Buildings Guide	2011-2012	Not directly quantifiable – indirect benefit
Implementation of the Growing Blacktown – Sustainable Local Food program including the development of a Local Food Policy	2011-2012	Not directly quantifiable – indirect benefit
Replace current air conditioning units with more energy efficient systems at 130 small sites owned by the Council	2011-2012	195 tons per annum
700kVA energy saving units at Council Civic Centre (voltage optimizer)	2011-2012	272 tons per annum
450kVA energy saving units at Emerton Leisure Centre (voltage optimizer)	2011-2012	272 tons per annum

Initiative	Year/s of implementation	Greenhouse Gas Reduction Outcome (in tons)
Install Building Management System at Council Civic Center East and South Wings	2011-2012	110 tons per annum
Development of a Sustainable Fleet Policy for Council	2011-2012	Not quantifiable
Retrofit T8 lighting to LED at selected sites	2012-2013	10 tons per annum
Retrofit dog kennel heaters to higher efficiency units at Council's Animal Holding Facility	2013-2014	46 tons per annum
Replacement of air conditioning systems in the south and east wings of the Council civic center.	2014-2015	239 tons per annum

This figure illustrates the cost per tonne of GHG reduction per measure. As this figure shows, the cost of the measures is varied. Based on this figure, the installation of energy saving units has been the most cost-efficient measure by the Council, as its cost per tonne of GHG reduction ranges from $132 for 350 KvA energy saving units in Blacktown stadium to $160 for 450 KvA unit in the aquatic center. The next cost-efficient actions have been retrofitting the dog kennel heaters to higher efficiency units, replacement of the electric hot water systems with solar hot water systems, and affixing the variable speed drives to pool motors with 217, 262, and 354 dollars per tonne of GHG reduction. In addition, the installation of a soft starter energy efficient pump for the wave pool has been the most expensive measure implemented by the Blacktown City Council, as its cost per tonne of GHG reduction has been $6875. After this, the least cost-efficient measures have been the replacement of South Wing air conditioning, upgrading of outdated and inefficient kitchen equipment and installation of energy meters at major sites, with $3967, $3750, and $2532 per tonne of GHG reduction, respectively.

Figure 57 shows a comparison between the payback times of the measures versus their cost per 0.01 tonne of GHG reduction. As this figure illustrates, the installation of 350 KvA energy saving units, with just one-year payback time has earned the first rank among the other 22 measures. In addition, its cost per 0.01 tonne of GHG reduction has been the least. Therefore, this measure was the most efficient action accomplished by the Council regarding both cost and GHG reduction and the best activity regarding its payback time. This is followed by affixing variable speed drivers to pool motors having just one-year payback period with a very low cost per 0.01 tonne of GHG reduction equal to $10.

On the other hand, the replacement of East Wing Air Conditioning, with 37 years of payback time has been the longest lasting payback action taken so far by the Council. In addition, its cost per tonne of GHG reduction has also been among the highest at $37.5 per 0.01 tonne of GHG reduction. The replacement of south wing air conditioning followed by upgrading of outdated and inefficient kitchen equipment has earned the next highest amount of payback time with 33.4 and 20 years, respectively. In addition, their cost per tonne of GHG reduction has been amongst the highest at $39.7 and $25.3 per 0.01 tonne of GHG reduction, respectively.

Overall, the figure shows that the payback period follows almost the same trend as cost per tonne of GHG reduction, except for the soft starter energy efficient pump, which has just 1.2 payback period and is amongst the lowest payback time; however, its cost per GHG reduction is among the highest at $68.8 per 0.01 tonne of GHG reduction.

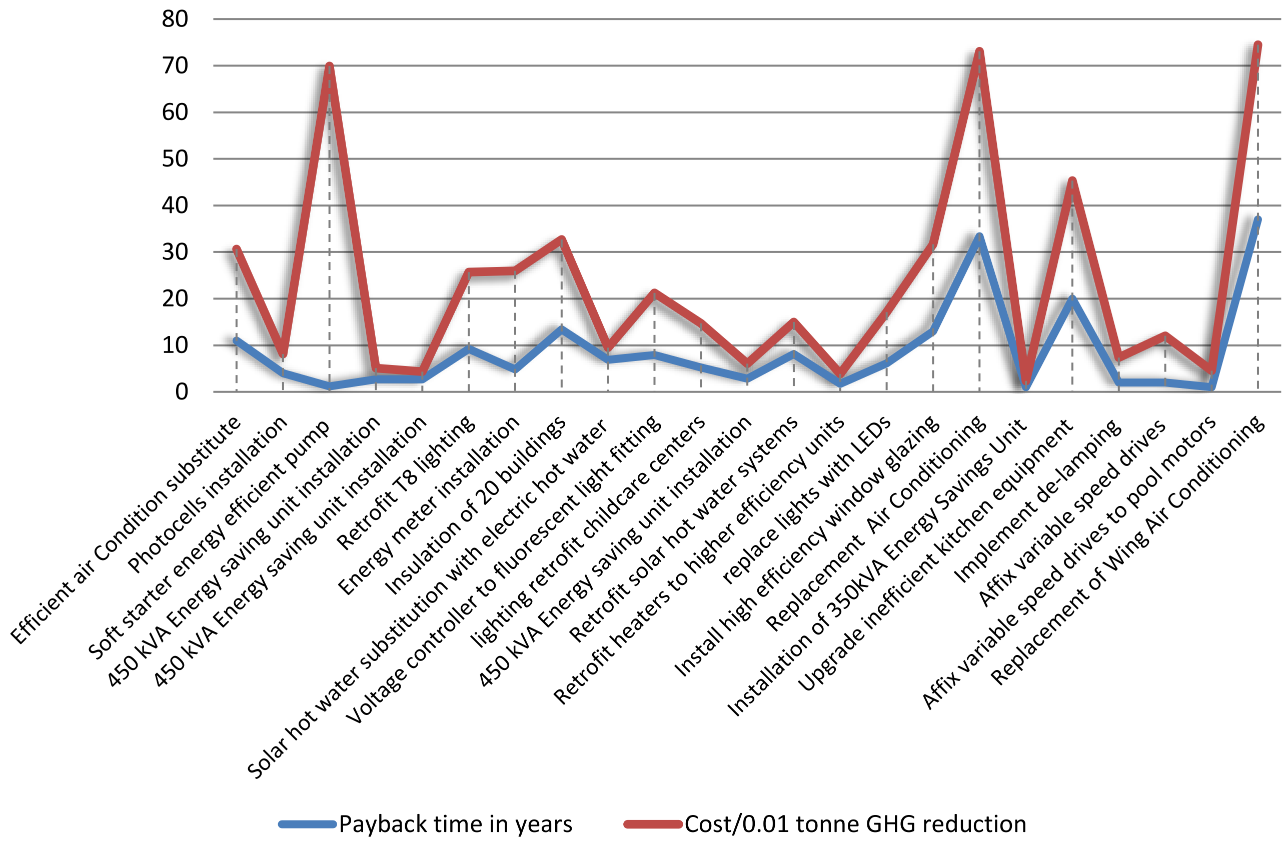


Figure 57: Comparison between payback times of the measures versus their cost per 0.01 tonne of GHG reduction

Figure 58 shows the Council's electricity saving per asset type in Mega Watt Hour (Mwh) from 2005 to 2017. The mitigation measures responsible for these savings are listed in Table 20. According to Figure 58, the highest saving was 54184 Mwh in the pools and aquatic centers followed by 37906 Mwh in the city center buildings. The highest electricity savings in the pools and aquatic center is probably because of the installation of the Variable Speed Driver (VSD) and solar hot water system, which reduce energy consumption considerably.

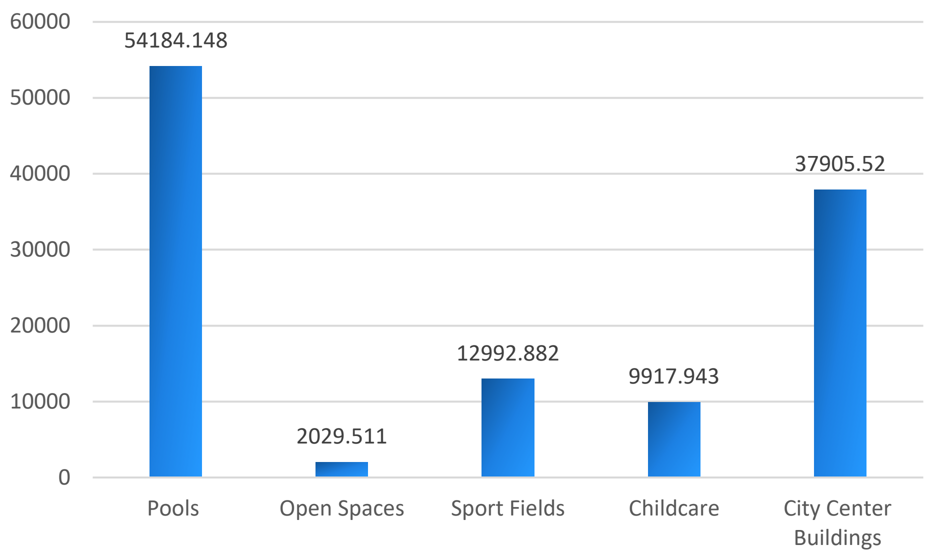


Figure 58: Electricity savings in the Council's assets from 2005 to 2017 based on asset type (Mwh)

In addition, Figure 59 illustrates the amount of gas saving per asset type in the study period, 2005- 2017. According to this figure, pools and aquatic centers save 423254 GJ of energy, which is 95% of the total saving of gas during the study period. In addition, city center buildings save 20401 GJ of energy from 2005 to 2017. According to the interview with the Council's experts and a review of the Council's documents, it can be concluded that the gas saving in the pools and aquatic centers was probably due to the installation of solar hot water systems. Furthermore, the gas saving in the city centers' buildings were the result of purchasing green power from an NSW supplier.

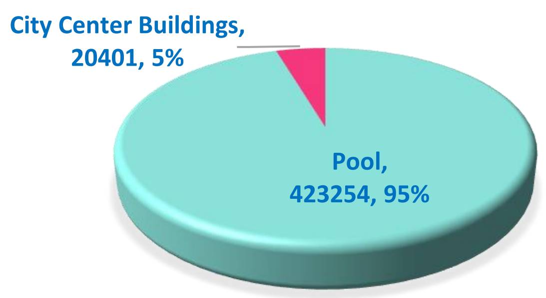


Figure 59: Gas savings in the Council's assets from 2005 to 2017 (Mwh)

4.3. Emission Forecast for 2015-2025 and the Planned Measures

The Council will continue to combat climate change adhering to the BCCAAP and its defined measures. This plan is now updating for the upcoming year to 2020 and will assist the Council in mitigating its GHG emission. A selection of relevant projects towards this goal for the period 2015-2025 is as follows.

- The "Cool Streets" pilot program, undertaking street retrofitting to combat climate change and the urban heat island effect in Blacktown.
- Community education programs on climate change aimed at addressing the needs of our community.
- Development of a Sustainable Procurement program, which will identify opportunities for Council to direct its capital investments and expenditure towards goods and services that will help the Council reduce its GHG emission and demonstrate corporate social responsibility.
- Management of a Revolving Fund, which will facilitate re-investment of savings by implementing further energy efficiency measures.

Table 21 outlines the proposed and completed actions of the Council for mitigating greenhouse gas emissions from 2015 to 2025. Each action listed in Table 21 of this Plan will be included in the Council's Works Improvement Plan Energy Management section and prioritized according to established criteria, and funded accordingly (Blacktown City Council, 2015a).

Table 21: Blacktown City Council's GHG mitigation action plan for 2015-2025

Row	Mitigation Action Description	Estimated lifetime (in years) of greenhouse gas reduction action	Estimated Greenhouse Gas (CO2e) tons reduction per annum	Cost – initial outlay	Anticipated payback time in years
1	Installation of 2 x 30 kW co-generation plants at Emerton Leisure Centre	15	TBD	TBD	TBD
2	Implement de-lamping in all buildings at 19 locations identified in 2010 energy efficiency audit	15	32	$11,000	3
3	Retrofit radio frequency control units in all offices to reduce energy consumption	15	10	$4,500	4
4	Installation of 200 kW gas-driven co-generation plant at Blacktown Leisure Centre	15	TBD	TBD	TBD
5	Install software to implement automatic switch-off of office equipment when not in use	10	3	$4,500	9
6	Installation of 65 kW multi-generation plant at Blacktown Aquatic Centre	15	TBD	TBD	TBD
7	Installation of 1,000 sqm solar absorption system at Blacktown Leisure Centre	15	312	$130,000	10
8	Installation of 350 sqm solar absorption system at Blacktown Aquatic Centre	15	109	$75,000	11
9	Ecovation Solar Photovoltaic - 9 x 10kW system (including credits from RECs)	15	153	$450,000	5
10	Installation of variable speed drives to motors at Mount Druitt Pool	15	15	$7,000	4
11	Installation of variable speed drives to motors at Riverstone Pool	15	15	$7,000	4
12	Installation of skylights in all buildings identified through energy efficiency audit in 2010	10	74	$361,000	40
13	Installation of 1,000 sqm solar absorption system at Emerton Leisure Centre	15	312	$200,000	10
14	Installation of 350 sqm solar absorption system at Riverstone Pool	15	109	$75,000	10
15	Installation of lighting transformers to 23 childcare centers	10	168	$213,000	10
16	Installation of 30kW co-generation plant at Mt Druitt Pool *	15	TBD	TBD	TBD
17	Installation of 30kW co-generation plant at Riverstone Pool *	15	TBD	TBD	TBD
18	Installation of bio-digester system to offset cooling and hot water heating	10	8	$19,500	20
19	Upgrade all existing field lights to metal halide	5	63	$232,000	30
20	Public Lighting - Retrofit all linear fluorescent lighting with LED	10	201	$445,100	18
21	Public Lighting - Replace all Metal halide flood lighting to solar powered LED (light-emitting diode)	5	117	$745,000	50
22	Public Lighting – Convert incandescent and fluorescent light fittings to LED	10	96	$365,000	192
23	Public lighting – convert low pressure sodium light fittings to LED	10	120	$120,000	8
24	Public lighting – convert metal halide light fittings to LED	10	958	$158,000	6
25	Installation of 2 x 200 kW co-generation systems at Blacktown Council Civic Centre *	10	TBD	TBD	TBD
26	Public lighting – convert one third of mercury vapor light fittings to LED	10	2,211	$2,700,000	8
27	Public lighting – convert one third of mercury vapor light fittings to LED	10	2,211	$2,700,000	8
28	Public lighting – convert high pressure sodium light fittings to LED	10	2,211	$2,700,000	8

5. Summary

This chapter introduced some green initiatives taken by the Blacktown City Council— the second most populous city in New South Wales—(Council, 2017) towards GHG emission mitigation and compares their level of emission control, costs, and payback periods. The period of this study was 2011 to 2016 and the data were from the audit process of the Council.

The measures implemented by the Council during the study period are as follows:

- Installation of solar power and solar panel systems.
- Implement energy and water efficiency measures at the Council's highest consumption sites.
- Replacement of current air conditioning and HVAC units with more energy efficient systems at 130 small sites owned by Council.
- Retrofit lighting to LED at the major sites.
- Partnership program and environmental education to the community on climate change mitigation and sustainable living.
- Development of Environmentally Sustainable Buildings Guide, Sustainable Events Policy, and Sustainable Fleet Policy.
- Install Building Management System at Council Civic Centers.
- Divert Blacktown City's residential waste collection to the Alternative Waste Treatment Facility to be composted and the methane generated used to produce renewable energy to power the facility.
- Purchase of Greenpower
- Regenesis carbon offset program – planting native carbon forests to offset carbon emissions.

Among all the actions of the Council during the study period, the installation of energy saving units has been the most cost-efficient measure, as its cost per tonne of GHG reduction ranges from $132 to $165 for 350 and $450 KvA energy saving units, respectively. The next cost-efficient actions have been retrofitting the dog kennel heaters with higher efficiency units, replacing the electric hot water systems with solar hot water systems, and affixing variable speed drives in pool motors.

In addition, the installation of a soft starter energy efficient pump for the wave pool has been the most expensive measure implemented by the Blacktown City Council, as its cost per tonne of GHG reduction has been $6875. After this, the least cost-efficient measures have been the replacement of South Wing air conditioning, upgrading the outdated and inefficient kitchen equipment and the installation of energy meters at major sites.

Considering the payback times of the measures, the installation of 350 KvA energy saving units, with only one-year payback time stands first among the 22 measures. After that, affixing variable speed drivers to pool motors with a one-year payback period has earned the second lowest payback time among the measures.

On the other hand, the replacement of East Wing air conditioning, with 37 years of payback time has been the longest lasting payback action taken thus far by the Council. In addition, its cost per tonne of GHG reduction has also been among the highest. Replacement of the south wing air conditioning followed by the upgrade of outdated and inefficient kitchen equipment, have earned the next highest payback times with 33.4 and 20 years, respectively. In addition, their cost per tonne of GHG reduction is amongst the highest.

In conclusion, the installation of energy saving units has been the most cost-efficient action of the Council, as its cost per tonne of GHG reduction has the lowest range from $132 for 350 KvA energy to $160 for 450 KvA unit. In addition, the payback time is only one year, which is reasonable. Based on the results of this research study and the latest energy audit of the Council's assets in 2017, several GHG mitigation measures can be proposed. The list of measures, electricity savings, energy savings, total cost, capital cost, payback period, and GHG savings are summarized in Table 22.

Future research in this field can be focused on developing an optimization model on the possible energy efficiency initiatives to achieve the maximum GHG reduction. If this problem can be solved, other types of measures with different conditions and various options can be modeled providing Councils with better conception of their emissions and develop more efficient action plans for reducing their GHG emissions.

Table 22: Proposed measures to reduce the Council's electricity consumption

Row	Description of opportunity	Electricity savings Mwh p.a	Energy saving as % of total consumption	Total cost savings $ p.a	Capital cost $	Payback period (years)	GHG savings tons CO2
1	Upgrade metal halide lamp with LED flood light- Lalor Park Library	3.5	7.7	$645	$1,250	1.9	2.9
2	Upgrade all fluorescent lights with LED lights- Mt Druitt bus Rail Interchange	41.9	62.0	$7,655	$15,150	2.0	35.2
3	Upgrade fluorescent tube lights, path lights and flood lights with LED lighting- Nurragingy	64.5	51.3	$11,231	$25,875	2.3	54.2
4	Upgrade lights with LED lights - Workshop, Blacktown International Sports Park	3.4	7.0	$604	$1,620	2.7	2.8
5	Upgrade remaining fluorescent tubes, bay lights and flood lights with LED lighting- Rooty Hill Depot	126.7	30.4	$17,229	$48,875	2.8	106.4
6	Upgrade flood lights with LED flood lights - Plumpton Park	10.5	79.5	$1,917	$5,560	2.9	8.8
7	Upgrade external flood lights and path lights with LED lighting - Emerton Leisure Centre	100.2	5.8	$10,816	$32,500	3.0	84.1
8	Upgrade existing lights to LED lighting - AFL stadium, Blacktown International Sports Park	51.2	10.2	$12,225	$37,870	3.1	43.0
9	Install motion sensors in toilets- 81-85 Flushcombe Rd Blacktown	7.1	0.4	$916	$3,000	3.3	6.0
10	Upgrade current lights to LED lights at various sports field amenity blocks	124.8	28.7	$22,829	$74,850	3.3	104.8
11	Selected lighting upgrade to LED of the Café at Blacktown Showground	2.7	7.0	$350	$1,200	3.4	2.3
12	Upgrade fluorescent lights with LED lighting - Max Webber Library, Blacktown	68.2	6.0	$8,250	$28,648	3.5	57.3
13	Upgrade fluorescent with LED lighting- 25 Childcare centers	39.9	5.8	$6,752	$23,871	3.5	33.5
14	Upgrade fluorescent lights to LED - 81-85 Flushcombe Rd Blacktown	248.4	12.4	$32,044	$115,126	3.6	208.7

Row	Description of opportunity	Electricity savings Mwh p.a	Energy saving as % of total consumption	Total cost savings $ p.a	Capital cost $	Payback period (years)	GHG savings tons CO2
15	Upgrade fluorescent and bay lights with LED lighting - Fire Brigade building Doonside	3.7	0.3	$685	$2,675	3.9	3.1
16	Upgrade existing lights to LED lighting - Athletics stadium	32.4	13.2	$5,733	$22,695	4.0	27.2
17	Install motion sensors, timers in toilets - 25 childcare centers	17.1	2.5	$3,131	$12,500	4.0	14.4
18	Upgrade florescent tubes and down lights with LED lighting- 49 Campbell (WSROC)	5.6	14.2	$1,025	$4,100	4.0	4.7
19	Upgrade existing lights to LED lighting - Football, Blacktown International Sports Park	24.0	25.2	$4,311	$17,285	4.0	20.1
20	Upgrade fluorescent tubes, down lights and flood lights with LED lighting - Mt Druitt library	52.9	14.2	$8,038	$32,792	4.1	44.4
21	Upgrade existing lights to LED lighting - Baseball stadium	27.9	9.7	$5,079	$21,135	4.2	23.4
22	Install motion sensors in toilets - Nurragingy Reserve	1.4	1.1	$236	$1,000	4.2	1.1
23	Upgrade existing lights to LED lighting- Softball stadium	15.4	7.9	$2,651	$11,340	4.3	12.9
24	Upgrade flood lights with LED lighting- Blacktown Arts Centre	40.7	53.3	$7,492	$32,195	4.3	34.2
25	Upgrade indoor sports lighting and florescent lights with LED- Rooty Hill Leisure	77.9	78.5	$7,007	$30,185	4.3	65.4
26	Install insulation (new and upgrade) to save on cooling and heating - Various locations	78.8	15.0	$65,363	$300,000	4.6	66.2
27	Upgrade florescent lights with LED lights - 71 Seven Hills Rd	6.0	3.5	$1,099	$5,150	4.7	5.0
28	Install two solar PV systems- selected Community Centers (Glenwood 10 kW; Riverstone 10 kW)	27.6	2.9	$5,051	$26,000	5.1	23.2
29	Appliances upgrade (fridge, dishwasher)- Arts Centre	2.0		$368	$2,250	6.1	1.7
30	Install 5 kW PV - 71 Seven Hills Rd	6.9	4.1	$1,069	$6,600	6.2	5.8

Row	Description of opportunity	Electricity savings Mwh p.a	Energy saving as % of total consumption	Total cost savings $ p.a	Capital cost $	Payback period (years)	GHG savings tons CO2
31	Install 200 kW solar PV system - Blacktown Leisure Centre Stanhope Gardens	278.5	14.0	$55,375	$364,747	6.6	233.9
32	Install motion sensors in toilets - Softball Stadium, Blacktown International Sports Park	1.0	0.3	$182	$1,200	6.6	0.8
33	Install 5 kW solar PV system - Lalor Park Library	7.0	15.3	$979	$6,506	6.6	5.8
34	Upgrade florescent/flood lights - 32 Community Centers	108.8	11.4	$19,905	$133,945	6.7	91.4
35	Install 40 kW solar PV system - Civic Centre	51.5	3.4	$7,669	$51,853	6.8	43.3
36	Install 30 kW solar PV system- Rooty Hill Depot	38.6	9.3	$5,752	$38,890	6.8	32.4
37	Install 100 kW solar PV system - Blacktown Library	128.8	11.4	$19,119	$129,535	6.8	108.2
38	Install solar PV- (216 kW capacity in total) on selected childcare centers)	290.1	30.3	$42,935	$296,400	6.9	243.7
39	Install motion sensors - Baseball, Blacktown International Sports Park	1.0	0.3	$172	$1,200	7.0	0.8
40	Upgrade fluorescent lighting with LED lighting- 22 Main St Blacktown	119.0	7.5	$14,215	$103,831	7.3	100.0
41	Energy efficiency - Small and general sites lighting upgrades with LED lighting- various locations (around 40 sites, subject to need for EE)	40.0	33.3	$7,320	$55,000	7.5	33.6
42	Replace old SKOPE display fridges (15 in total) with energy efficient fridges- Selected Community Centers	27.0	2.8	$4,941	$37,500	7.6	22.7
43	Install 70 kW solar PV system - 22 Main St Blacktown	90.2	5.7	$11,634	$90,694	7.8	75.8
44	Install 100 kW PV - 81-85 Flushcombe Rd Blacktown	138.1	6.9	$15,195	$129,535	8.5	116.0
45	Install motion sensors (estimated 140) - 62 Sports fields toilets and change areas	12.5	2.9	$2,283	$21,000	9.2	10.5
Total		**2,645**	**15.5**	**$459,478**	**$2,405,133**	**5.2**	**2,222**

CHAPTER 9

The GHG Emission Reduction Toolkit

SUMMARY

as the heart of this thesis, introduces the GHG emission reduction toolkit in four pre-defined categories. This chapter summarizes the carbon reduction strategies of other chapters, and takes a step forward to present a comprehensive GHG mitigation toolkit by reviewing the associated literature.

1. Introduction

As explained in the introduction, the main purpose of this thesis was to develop a toolkit that reduces the GHG emission. This toolkit is a list of potential measures through them the city councils can mitigate their GHG emissions. The toolkit is not on the scale of a policy document to determine the long-term strategy of the Council, neither is it an action plan to deal with the short-term specific plan. Instead, this toolkit is a medium scale document to determine possible actions.

Essentially, the toolkit is a shortcut to the specific needs of communities as per their conditions. By providing a list of actions in addition to their GHG reduction potential, it becomes possible to fit the priorities to the identified communities.

A good approach for using this toolkit is to select actions that can fit the society in the strategy development phase. The authorities, experts, and local communities should examine this stage through this toolkit and choose realistic actions for their communities. Subsequently, local communities and the associated authorities should provide the necessary funding to move from the planning process to implementation. It is better to source the funding through sharing between the local community and the government, to guarantee its proper implementation and continuous maintenance (United Nations University, 2012). The toolkit looks like a workbook and provides the user with the areas requiring improvement and brainstorming. Hence, the tools detailed here are generalized. It is recommended that communities justify it as per their needs and translate it into their own language.

Considering the proposed actions, communities should focus on various areas, which could vary from residential energy to landfills, and waste, and even transportation. For instance, wherever in this toolkit specific actions were proposed to reduce GHG emission in residential energy consumption, it is a general idea that should be justified as per the local conditions of the selected region. This is a list of the potential actions, which acts as a guideline. It is practically recommended to contrasting the suggested actions with other high-level strategic documents to find complementary priorities.

2. Process of Using the Toolkit

This toolkit provides exercises and information about the potential initiative to mitigate GHG emissions at the regional and urban scale. For this purpose, it requires an assessment of the GHG emission baseline inventory at the selected region. Since any proposed reduction needs to be undertaken in a participatory process, all the potential stakeholders need to be engaged from the very first stages. The process is presented into six major pieces, as outlined below. Step 2 and 3 are the heart of the process and will consume the most significant amount of time and resources. Those steps are further expanded in the graphic on the following page and are the focus of the toolkit (Association of Bay Area Government, 2018a).

Ongoing Engagement

This step includes identifying the stakeholders from various parties, regions, or groups, prioritizing and involving them in the planning, implementation, and evaluation process which is called "ongoing engagement" (Association of Bay Area Government, 2018b).

Identify the Plan

This step includes engaging the associated experts from different parties to study the toolkit and select the most suitable plan, which matches not only their area but also has impact on the surrounding environment.

Develop Strategies

This step includes developing a strategy or a group of strategies based on the selected plan. This strategy/ strategy should be compatible with the high-level documents of the selected case study and should address community vulnerabilities.

Take Action

This step includes the creation of an annual, quarterly, and sometimes, monthly action plans to ensure that the strategies will translate into actions.

Evaluate Results

This step includes evaluating and refining strategies and actions plans during the time period to keep its relevancy and applicability.

Implementation

This step includes the implementation of the selected plan, which has been justified to the climate condition and collated with relevant strategies.

Figure 60 illustrates the step-to-step process of using this toolkit and the orders of actions. According to this figure, this process is not a linear one, but a loop of actions starting from identifying the plan and finishing with the same action. Therefore, any plan that has been identified, developed, and taken to action after evaluation, can be changed, stabilized, or differed.

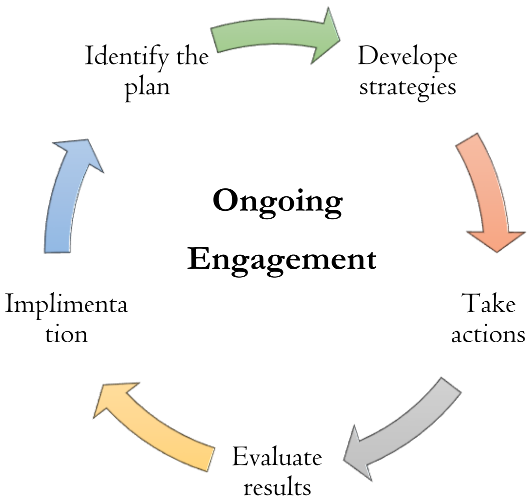


Figure 60: Step-by-step process of using this toolkit

Figure 61 illustrates the detailed process of implementing a proposed plan of the toolkit. As this figure shows, the first step in implementing any suggested plan from the toolkit is laying the groundwork, which includes creating the team and network, developing the sustainability goals, and defining the scope. In the next step, which is identifying the methods, the baseline of the system is determined, the proposed target is specified, and an impact assessment for the proposed plan is undertaken. In the next stage, the required asset needs to be identified and categorized and the essential funding to supply them should be determined. When the baseline is ready, the methods are clarified and the source of asset determined, it is then time to conduct the assessment. In this stage, the profile sheets are developed, the assessment questions are determined, and the exposure analysis is conducted. Finally, the implementation plan is developed. In this final step, the action plan for each strategy is established, the roles and responsibilities are determined, and the timeframe is extracted for each action.

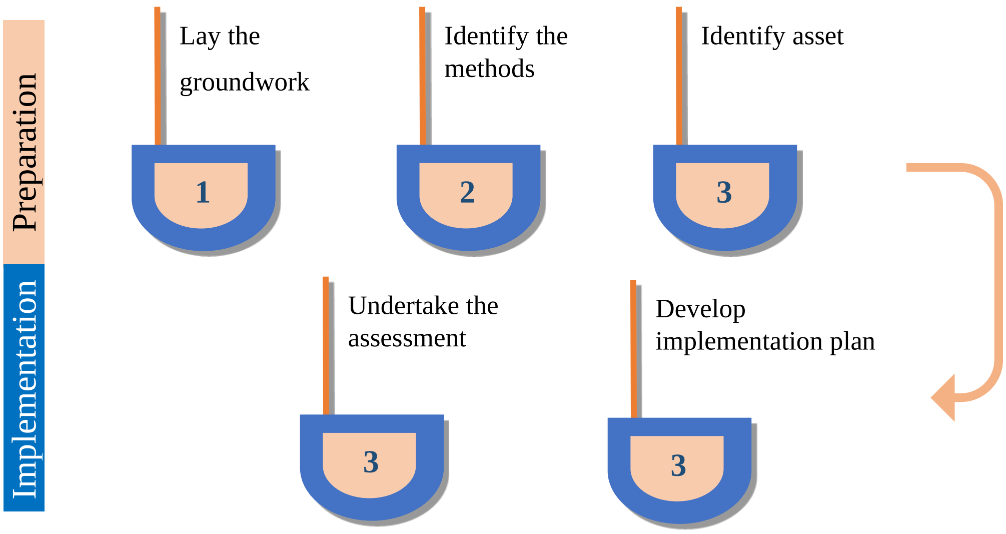


Figure 61: Detailed process of implementing a proposed plan of the toolkit

3. Definition and Key Concepts

This toolkit proposes a wide range of actions for mitigating the GHG emission in the four sectors listed below. These four sectors are selected on the basis of the main chapters of this study. These four sectors was selected according to the main contributors of the GHG emission at the urban scale (Erickson, Lazarus, Chandler, & Schultz, 2013; Menges, Gruen, & Read, 2017). This toolkit refers to them as technical tools. There may be lot of capacity building, raising awareness, promotional and educational tools, which are beyond the scope of this research. A separate study can investigate the cultural, behavioral, and social methods.

- Sector 1- Transportation
- Sector 2- Waste Management
- Sector 3- Urban Lan duse
- Sector 4- Energy Management

The toolkit also ranked all the actions based on their potential for GHG reduction. In addition, some other elements have been added to the toolkit specifying the co-benefit of each action and its time frame. The following are the key concepts of the toolkit:

- **Sector/ Sub-sector:** GHG emissionThis section represents the main sector from which GHG is emitted and the whole sub-sectors under that The main 4 sectors were listed above and the associated sub-sectors are represented in the tables.

- **Technology/ Initiative:** The specific program in the smallest possible scale, which together with the other actions, assists in achieving the GHG abatement objective.

- **Abatement Potential:** This criterion is defined for each action and shows the extent of mitigation of GHG emission in the context of an objective. GHG reduction potential is represented on the Low, Medium, High scales. Methods for evaluation of urban-scale GHG reduction are still in their very new stage, and very few reviews or meta-analyses of urban-scale GHG abatement exist (Erickson et al., 2013). To develop a consistent range of reduction potential at the city scale, a widely cited international studies of global GHG abatement potential, was used in this study and listed in Table 23. The references used for estimating the GHG abatement potential of new technologies is presented in the table; however, the following four resources were widely used in this study to estimate the reduction potential of the introduced initiatives. All abatement potential was estimated relative to the average world resident's GHG emission, which was calculated based on forecasts of CO2 at the global scale.
    - (Menges et al., 2017)
    - (Erickson et al., 2013)
    - (International Energy Agency, 2017)
    - (Practice Greenhealth, 2018)

Reduction from scope: This section represents the potential scope the GHG will be taken from. According to (World Resources Institute, 2017)there are three main scopes producing Greenhouse Gases includes Scopes 1, 2, 3. Scope 1 covers direct emissions from owned or controlled sources. Scope 2 covers indirect emissions from the generation of purchased electricity, steam, heating and cooling consumed by the reporting company. Scope 3 includes all other indirect emissions that occur in a company's value chain.

- **Policy Recommendation:** This section represents the policy recommendation for undertaking each new technology. This part also indicates the required policy infrastructure to introduce, launch or implement the proposed technologies.

For using the toolkit, a reference table (Table 23) was provided representing the main sources of the toolkit. A unique code was allocated to each reference, which will be used further in the toolkit. This table also highlighted the main feature of the resources, the country of the corresponding author and the year of publication.

5.1. Main sources of the GHG emission reduction toolkit

Table 23: Main sources of the GHG emission reduction toolkit

Article	Code	year	Country (Affiliation of corresponding author)	Highlights	Sectors	Citation
Multi-criteria decision analysis in policy-making for climate mitigation and development	1	2019	South Africa	- Paris agreement - Policy making - multi-criteria decision analysis	- Transport - Energy Management - Waste Management - Land Use	- (Cohen et al., 2018)
Strengthening National Legal Frameworks to Implement the Paris Agreement	2	2018	UNEP	- Good Climate Laws - Low-carbon development	- Law - Energy Management - Transportation - Gender	- (Manguiat & Raine, 2018)
Adaptation of California's electricity sector to climate change	3	2012	USA	- Energy demand - Electricity Supply - Renewable energy sources - Improve system resiliency	- Energy management	- (Vine, 2011)
The tools of climate adaptation policy: analysing instruments and instrument selection	4	2016	Canada	- Public policy - Policy instruments - Ways to avoid policy interplay	- Public policy	- (Henstra, 2015)
Public Financial Institutions and the Low-carbon Transition	5	2014	Europe	- Public financial institutions - Investment - Climate finance	- Green Finance	- (Cochran, Hubert, Marchal, & Youngman, 2014)
Literature review of green retrofit design for commercial buildings with BIM implication	6	2015	Hong Kong	- Energy efficiency - Design framework - Green retrofit	- Energy management	- (Bu et al., 2015)

Article	Code	year	Country (Affiliation of corresponding author)	Highlights	Sectors	Citation
				- Process design		
Carbon neutral Biggar: calculating the community carbon footprint and renewable energy options for footprint reduction	7	2008	USA	- Carbon footprint - Carbon offsetting - Emissions Modelling - Renewable energy - Wind energy	- Energy management	- (Barthelmie, Morris, & Schechter, 2008)
Mobilizing Private Investment in Sustainable Transport	8	2013	OECD	- Transport - Infrastructure - private investment - climate finance - transport policy - urban planning	- Transport - Green Finance	- (Ang & Marchal, 2013)
On the Integration of Leadership in Energy and Environmental Design (LEED)® ND Protocol with the Energy Planning and Management Tools in Italy: Strengths and Weaknesses	9	2013	Italy	- Urban sustainability - energy efficiency - energy planning; - sustainable energy action plan (SEAP);	- Energy management	- (Dall'O, Galante, Sanna, & Miller, 2013)
Co-benefits of Replacing Car Trips with Alternative Transportation: A Review of Evidence and Methodological Issues	10	2013	Australia	- motor vehicle emissions - ecofriendly transport - d active transport	- Transportation	- (Xia, Zhang, Crabb, & Shah, 2013)
A new approach to carbon reduction	11	2012	USA	- Carbon reduction strategies - the climate action plan	- Transportation	- (X. Li & Kellenberg, 2012)

Article	Code	year	Country (Affiliation of corresponding author)	Highlights	Sectors	Citation
Several Thoughts on GHG Emission Reduction and Traffic Congestion Control in Urban Transport	12	2011	China	- urban transport - emission reduction - traffic congestion control	- Transportation	- (X. Chen, Jiang, & Li, 2011)
Scenarios for the use of GHG-reduction instruments- How can policy- instruments as carbon emission trading and tradable green certificates used simultaneously for reach a common GHG reduction target?	13	2000	Denmark	- Policy instruments - tradable green certificates - tradable GHG emission quotas - GHG-credits	- Policy Instruments	- (Morthorst, 2000)
GHG emission reduction in buildings- The need for further policy beyond emission trading	14	2008	Australia	- Carbon Pollution Reduction Scheme (CPRS) - emissions trading - National framework on Energy Efficiency - split incentives	- Policy frameworks	- (Pears, 2008)
GHG emission reduction in energy sector and its abatement cost: Case study of five provinces in Mekong delta region, Vietnam	15	2018	Vietnam	- Energy efficiency - renewable energy	- Energy Management	- (Luu, Nguyen, Halog, & Bui, 2018)
Green House Gases (GHG's) Emission Reduction Measures and Verification Challenge at Transport Sector	16	2018	Indonesia	- Area Traffic Control System - traffic impact control - Parking management - Bus Rapid Transit (BRT) system	- Transport	- (Setiadji et al., 2018)

Article	Code	year	Country (Affiliation of corresponding author)	Highlights	Sectors	Citation
				- smart driving - Non-motorized transport		
GHG emission scenarios in Asia and the world: The key technologies for significant reduction	17	2012	Japan	- Solar power generation - Wind power generation - Biomass power generation - Biofuel	- Renewable energy	- (Akashi, Hijioka, Masui, Hanaoka, & Kainuma, 2012)
Case Study of a Nearly Zero Energy Building in Italian Climatic Conditions	18	2017	Italy	- Energy modelling; climatic conditions - Sustainable materials - Insulation - Air infiltration; - Photovoltaic cells	- Renewable energy - Energy Management	- (Khan, Asif, & Mohammed, 2017)
Greenhouse Gas Reduction Toolkit	19	2015	USA	- Energy supply - Residential energy - Commercial energy - Vehicles and transportation - Waste and landfill - Aviation and airport	- Policy Instrument	- (Menges et al., 2017)
Combating Climate Change: Energy Saving and Carbon Emission Reduction in Buildings	20	2011	Hong Kong	- Buildings Energy Efficiency Ordinance - Energy Efficiency - Building Regulation.	- Energy Management	- (Council for Sustainable Development, 2011)
Technologies, policies and measures for GHG	21	2013	USA	- urban climate change mitigation	- Policy frameworks	- (Erickson et al., 2013)

Article	Code	year	Country (Affiliation of corresponding author)	Highlights	Sectors	Citation
abatement at the urban scale				- accounting frameworks GHG management - mitigation measures		
Tracking Clean Energy Progress 2017	22	2017	International Energy Agency	- Energy Technology Perspectives - Informing Energy Sector Transformations	- Policy frameworks	- (International Energy Agency, 2017)
Greenhouse Gas Reduction Toolkit	23	2018	USA	- Setting greenhouse gas reduction goals to protect health - Conducting a GHG inventory - and tracking reductions	- Policy frameworks	- (Practice Greenhealth, 2018)
Vehicle Routing Optimization for Improving Fleet Fuel Efficiency: A Case Study in Sydney, Australia	24	2017	Australia	- Fleet fuel efficiency - vehicle routing problem - transportation	- Transport	- (Karimipour et al., 2017)
Quantifying the effects of general waste reduction on greenhouse-gas emissions at public facilities	25	2019	Australia	- municipal solid waste - GHG emission reduction from landfill waste	- Waste management	- (Karimipour, Tam, Burnie, & Le, 2019)

5.2. Toolkit-Transport

GHG emission in this sector is associated with the combustion of fossil fuel in vehicle engines. The types of vehicles range from personal cars to heavy-duty vehicles. The focus of this study was on heavy-duty vehicles; however, some recommendations can be utilized for lighter vehicles as well. Opportunities in this sector include any initiative to reduce fuel combustion, smart navigation, improving vehicle efficiency, and using biofuels. The co-benefit of the actions in this sector mostly focuses on public health and developing the green industry.

Sector	Subsector	Technology/ Initiative	Abatement Potential	Reduction from Scope	Article Codes	Policy Recommendation
Transport	Public Transport	Bus Rapid Transit (BRT)	Medium	1	1,2, 8	- CO2 emissions targets for new vehicles - Promote green business and consumer engagement - Parking restriction - Provisions for Public Access to Information and Participation
		Light Rail/Metro or Mass Rapid Transit (MRT)	Medium	1	1, 8, 16	
		Electric train procurement	High	1	1, 8, 16	
	Non-Motorized Transport	Shared-use vehicle and bicycle systems	Medium	1	8, 12, 19	- Implementing the policy of traffic congestion fee - Promoting the establishment of a market system
		Increased active travel	Medium	1	10, 12, 19	
		Replacing car trips by bicycle	Medium	1	10, 19	
	High efficiency/ Hybrid vehicles	Lower-carbon emission motor vehicles	High	1	2, 10, 22	- Promoting the establishment of a market system - CO2 emissions targets for new vehicles
		More efficient engines	High	1	2, 10, 22	
		Hybrid electric vehicle (HEV)	High	1	12, 22	

Sector	Subsector	Technology/ Initiative	Abatement Potential	Reduction from Scope	Article Codes	Policy Recommendation
Transport		Alternatives sources of fuel, such as biofuel and low Sulphur diesel	Medium	1	10, 12, 17, 22	- Providing access to long-term capital - Redirecting financial flows: Mainstreaming a transition to a low-carbon economy across activities and business-lines - Creating new markets
		Adaptation to new European standard for combustion of fuel	Medium	1	5, 22	
		Fuel efficiency monitoring plan to check the performance of the combustion system periodically	Low	1	5, 22	
	Technical Improvement/ Eco-driving	Vehicles' Weight reduction	Medium	1	17, 21	- Develop educational programs for heavy-duty vehicle drivers to make them familiar with environmentally friendly style of driving - Provisions for Public Access to Information and Participation - Creating new markets
		Engine friction reduction	Medium	1	17, 21	
		Aerodynamic drag reduction	Medium	1	17, 21	
		Rolling resistance reduction	Medium	1	17, 21	
		Brake drag reduction	Medium	1	17, 21	
		Continuously variable transmission	Medium	1	17, 21	
		Diesel Particulate Filters in heavy-duty vehicles	Medium	1	2, 21	
		Diesel Oxidation Catalysts in heavy-duty vehicles	Medium	1	19, 21	
		Maintenance system for heavy vehicles to test the tires, engine system, gearbox and …regularly	Medium	1	2, 21	
		Simulation model to obtain the optimum speed- Acceleration	Low	1	16, 21	

Sector	Subsector	Technology/ Initiative	Abatement Potential	Reduction from Scope	Article Codes	Policy Recommendation
		and braking times for each heavy-duty vehicle				
		Truck maintenance checklist for drivers to report their vehicles' status regularly	Low	1	16, 21	
	SMART Transportation System	Transportation Demand Management	Medium	1, 3	11, 21	
		Commute Trip Reduction Programs	Medium	1	11, 21	
		Enhanced Transport Demand Management (TDM)	Medium	1	12, 21	
		Intelligent Transportation System (ITS)	High	1, 3	16, 12	
		Traffic Impact Control/TIC	Medium	1, 3	16, 23	
		Heavy vehicle management system (To help trucks are not over-loaded/under-loaded)	Medium	1	19, 21	
	SMART Transportation System	Heavy vehicle integrated networking system to help them to cover each other, and reduce un-necessary travel)	High	1, 3	19, 24	- Providing and building capacity & expertise - Redirecting financial flows: Mainstreaming a transition to a low-carbon economy across activities and business-lines
Transport		Smart navigation system across the heavy vehicle fleet to optimize their routes	High	1	19, 24	
		Reduce the empty running intervals (Proportion of kilometers that are run empty)	High	1	19, 21	

Sector	Subsector	Technology/ Initiative	Abatement Potential	Reduction from Scope	Article Codes	Policy Recommendation
	Infrastructure	Reduced Parking Footprint	Medium	3	9, 13, 19	- Providing access to long-term capital - Redirecting financial flows: Mainstreaming a transition to a low-carbon economy across activities and business-lines - Carbon emission trading - Creation of a Coordination Mechanism or Oversight Body/Entity - Facilitate EV bulk purchase program - Create or expand no car zones
		Enhance Street Green Network	Medium	3	9, 13, 19	
		Increase EV charging stations in visible, accessible locations	Low		22, 23	
		Bicycle and Pedestrian Network Enhancements	Medium	3	2, 11, 19	

5.3. Waste Management

GHG emission in this sector comes from the gathering the waste, transporting it to the collection center, transporting it to the landfills or recycling centers and the landfilling and recycling process. According to the scope of this research, the proposed toolkit focuses on waste minimization and waste transportation. GHG emissions from waste transportation come from the combustion of fossil fuel, processing waste on-site, and lifting waste bins. Opportunities to reduce emissions in this sector include diverting or salvaging organic components of the waste stream and increasing the efficiency of hauling and processing. Since any initiative for reducing the waste at the generation point will mitigate any further need for landfilling, the rest of this toolkit concentrates on minimizing, sorting, or eliminating the general waste at the generation point. The co-benefits of successfully reducing the waste and optimizing the waste transportation include the potential for inter-governmental collaboration, developing the green industry, and enhancing public health and safety.

Sector	Subsector	Technology/ Initiative	Abatement Potential	Reduction from Scope	Article Codes	Policy Recommendation
Waste Management	Composting	Equip an entity such as the landfill with resources to turn organic waste into a safe and usable compost product	High	3	1, 19	- Run ongoing public education campaigns to promote composting - Require waste haulers to offer compost pickup - Ensure buildings have adequate space for composting and recycling collection and storage - Create composting program and infrastructure for multifamily complexes
		Provide a suitable and sufficient space for onsite composting and store the recycling waste	High	3	19, 23	
		Eliminate organic food from the waste stream by introducing separate collection bins	Medium	3	19, 23	

Sector	Subsector	Technology/ Initiative	Abatement Potential	Reduction from Scope	Article Codes	Policy Recommendation
	Landfilling	Waste management strategy and plan for each region	Medium	NA	5, 19	- Providing access to long-term capital - Providing and building capacity & expertise - Provisions for Public Access to Information and Participation
		Accessible compost drop-off locations	Low	NA	2, 19	
		direct use of landfill gas	High	1	2, 19	
		flaring landfill gas	High	1	17, 19	
		electricity and heat generation from landfill gas	High	1	17, 19	
	Recycling	Improve or enhance the infrastructure for recycling and composting	Low	NA	19, 25	- Provide resources and support for property managers to increase recycling and composting - Raise awareness strategies for different age groups - Advertising waste reduction methods through social media and networking programs - Door-to-door visits to educate the public on reducing, separating, and eliminating their waste on-site - Develop programs to reduce use of plastic foodservice packaging
		Joining related programs to collect and recycle particular wastes, such as coffee cups, plastic bags and…	Low	NA	19, 25	
		Establish reuse center for building materials	Medium	NA	19	
		Require recycling and compost bins at public events	Medium	NA	19, 23	
	Waste Collection	Equip the waste collectors to lift the recycle and organic waste separately	Medium	3	5, 25	- focus on R&D and commercialization, favoring “Energy Turnaround” projects
		Equip waste collectors with the smart navigation system	High	1	5, 25	

Sector	Subsector	Technology/ Initiative	Abatement Potential	Reduction from Scope	Article Codes	Policy Recommendation
		Reduce the intervals of waste collection by introducing smart bins	Medium	1	5, 19	- Redirecting financial flows: Mainstreaming a transition to a low-carbon economy across activities and business-lines
		Develop a maintenance system for waste collectors to ensure optimum performance	Medium	1	5, 25	

5.4. Urban Land use

In this section of the toolkit, the focus is on urban planning, and capacity development for reacting to the climate change at urban scale. Land use may not have a direct impact on climate change, but the functions of the cities, can change dramatically by variations of their structures. For instance, a compact development, would reduce the need for resident's movement in the city, as well as the local markets and food hubs. Or housing and job proximity, would help to a considerable amount of on-road travel, while in the same time will reduce spent time on the roads. Another type of initiatives in this part, could be those associated with tree planting and greener cities. Lined and shadow streets and permeable pavement are some examples of this kind; which provide high albedo surface, while at the same time make the cooler, greener cities.

Sector	Subsector	Technology/ Initiative	Abatement Potential	Reduction from Scope	Article Codes	Policy Recommendation
Land Use	Structural Intervention	Connected and Open Community	Medium	NA	2, 9	- Enhance Environmental Impact Assessment Laws at the city level - Targeted subsidies to promote sustainable neighborhood - Providing and building capacity & expertise
		Smart Location & Linkage	Medium	1	9	
		Housing and Job Proximity	Medium	NA	9, 23	
		Walkable Streets	Medium	1	9	
		Compact Development	Medium	1, 3	9, 5	
		Mixed-Use Neighborhood Centers	Medium	1, 3	9, 5	
		Local Food production	Low	1, 3	9, 23	
		Lined and Shadowed Streets	Low	NA	9, 5	

Sector	Subsector	Technology/ Initiative	Abatement Potential	Reduction from Scope	Article Codes	Policy Recommendation
		light/ permeable/ High albedo pavements	Low	NA	19, 23	
		Increase shade at the street level	Low	NA	19	
		Evaporate cooling system and surface water for dry cities	Low	NA	19, 23	
		Misting fan technologies for dry and crowded regions	Low	NA	19	
	Functional Intervention	Neighborhood Pattern and Design (NPD)	Medium	NA	8	- Providing and building capacity & expertise - Creation of a Coordination Mechanism or Oversight Body/Entity - Mainstreaming Climate Change into Development Strategies
		Sustainable Zoning	Medium	NA	2, 5	
		Land-use planning	Medium	NA	8, 23	
		Strategic Urban Planning	Medium	NA	2, 21	

5.5. Energy Management

The GHG emission in this sector comes from electricity and natural gas. As this research study focuses on the Council's asset, the tools also focus on the commercial energy sector, such as official buildings, sports centers, community centers, childcare centers, and libraries. The toolkit covers the requirements of the various assets of different ages and conditions. Opportunities to reduce GHG emission consume less energy by increasing energy efficiency, retrofitting, replacing old appliances with new ones, and utilizing renewable energy. The co-benefits of successfully mitigating the GHG emissions from this sector include the potential for developing the green industry and enhancing public health and safety.

Sector	Subsector	Technology/ Initiative	Abatement Potential	Reduction from Scope	Article Codes	Policy Recommendation
Energy Management	Renewable Energy	Solar power generation	High	2	3, 13, 22	- Targeted subsidies to promote use of renewable energies - focus on R&D and commercialization, favoring "Energy Turnaround" projects - Providing access to long-term capital - Providing and building capacity & expertise - Redirecting financial flows: Mainstreaming a transition to a low-
		Wind power generation	High	2	3, 17, 22	
		Biomass power generation	High	2	17, 13, 22	
		Biofuel/ Biomas power generation	High	2	3, 15, 22	
		Micro-wind power generation	High	2	2, 7, 9, 22	
		Solar flat plate	High	2	5, 7, 22	
		Solar evacuated tube	High	2	2, 5, 7, 22	

Sector	Subsector	Technology/ Initiative	Abatement Potential	Reduction from Scope	Article Codes	Policy Recommendation
		Photo voltaic cells	High	2	7, 17, 22	carbon economy across activities and business-lines - Carbon emission trading - Mainstreaming Climate Change into Development Strategies
		Solar thermal water heaters	High	2	15, 17, 22	
Energy Management	Energy Efficiency	Peak demand management	Medium	2	3, 9, 22	- Enacting mitigation policies that enhance adaptation potential - Encourage large consumers to retrofit their assets by providing them special incentives - Develop programs for historical and commercial buildings to meet the new building or energy codes - Make the energy assessment a requirement for all old buildings - Adapt buildings with peak time requirement of the Green Star standard
		High-performance air-conditioners	High	2	15, 23	
		High efficiency lighting systems	Medium	2	15, 22	
		High efficiency cooling/ heating systems	High	2	17, 21	
		High-efficiency/ LPG/ Gas systems	High	2	17, 9, 21	
		High-efficiency water heater	High	2	17, 21	
		Energy saving units at large buildings	High	2	5, 21	
		Building Management System for large buildings	Medium	2	20, 19	

Sector	Subsector	Technology/ Initiative	Abatement Potential	Reduction from Scope	Article Codes	Policy Recommendation
Energy Management	Energy Efficiency	Variable speed drives for the pools and aquatic centers	High	2	5, 21	- Targeted subsidies to increase energy efficiency ambition - Providing access to short-term capital - Providing and building capacity & expertise - Redirecting financial flows: Mainstreaming a transition to a low-carbon economy across activities and business-lines - Enhance green building codes of conduct
		Lighting transformers for the buildings	Low	2	2, 22	
		Radio frequency control units on official buildings	Medium	2	3, 22	
		Tune the burners/ Cooling and Heating systems regularly	Medium	2	3, 19	
		Economizers for the boilers, and the other heating systems	High	2	20, 21	
		Integrate the heating system with air conditioning system	Medium	2	5, 23	
	Setting Standards/ Research and Development	Energy certification for existing houses	High	NA	1, 2	- Enacting mitigation policies that enhance adaptation potential - Make the energy assessment a requirement for all old buildings - focus on R&D and commercialization, favoring "Energy Turnaround" projects
		Energy action plan for existing and new buildings	Low	NA	3, 23	
		Net-billing program	Medium	NA	3, 19	
		Increasing R&D to support energy sector response	Medium	NA	1, 2, 22	
		Municipal Energy Plans (MEP)	High	NA	3, 9, 22	

Sector	Subsector	Technology/ Initiative	Abatement Potential	Reduction from Scope	Article Codes	Policy Recommendation
		Sustainable Energy Action Plans (SEAP)	Medium	NA	3, 19	- Mainstreaming Climate Change into Development Strategies

CHAPTER 10

Key Recommendation for Using the Toolkit

SUMMARY

This chapter presents the key recommendations for using the introduced toolkit in chapter 9. This chapter introduces the international implications of this research study and its applicability in other regions, in addition explains the significance of community engagement in the toolkit's planning and implementation process. Also, it describes the process toward delivering a policy framework for execution of the toolkit and presents a monitoring and evaluation plan for assessing the toolkit's implementation process.

1. International Implication

A toolkit should adapt to fit the needs of communities and vary in terms of carbon reduction potential, feasibility, cost, associated co-benefits, and more, and will have an international implication. It is not justified for a small region in Australia; however, it can extend to adapt to other regions in the world. Therefore, the actions were not quantified but is provided by a list of opportunities for the cities around the world to mitigate their GHG emission.

According to the Association of Bay Area Government (2018a), engaging stakeholder is "…the process of working collaboratively with and through groups of people affiliated by geographic proximity, special interest, or similar situations to address issues affecting the wellbeing of those people…It often involves partnerships and coalitions that help mobilize resources and influence systems, change relationships among partners, and serve as catalysts for changing policies, programs, and practices.

The toolkit is also useful as a basic document for regional collaboration considering that any action in a given region can have greater impact on the surrounding environment. By creating a network of local and regional communities of the neighborhood countries, cities, or states, it will be possible to form a climate change collaboration to achieve greater benefit for each individual member. This is where this toolkit can be beneficial, allowing adjacent areas come together under open guidelines to mitigate their GHG emission, while strengthening regional collaboration.

Based on this definition, it is essential that neighboring regions engage in a mutual planning process in mitigating the impacts of climate change from inception to implementation. The relationships developed during such an engagement planning process will be different from a plan that is never executed. Therefore, this toolkit will provide fundamental information on GHG emission reduction to enable the development of communications, agendas, and meetings.

Another international implication of developing such a toolkit, is to provide a regional effort for a global problem. National climate policies might be ineffective in reducing local level carbon emission. A set of various policies is investigated in 4 major emitters of greenhouse gases with particularly high consumption-based emissions: Transportation, Urban Land Use, Waste and Energy sectors. As it is clear in section 5 of this chapter, a comprehensive set of the policy recommendation were also proposed to bridge any of the suggested tool to its equivalent policy. It is tried choose and propose those universal policies to be compatible for other regions in the globe.

2. Community Engagement

The local community must choose a plan to prioritize for implementation. It is significant that authorities or leaders provide a supportive culture and necessary resources for success (Association of Bay Area Government, 2018b). These recommendations for decision-makers assist in the overall mitigation of climate change impacts and ensure that the community will be kept engaged:

- Maintain the essential organizational capacity.
- Ensure that stakeholders are engaged in the whole process.
- Introduce champions when the plans were finalized.
- Identify the sources of funding for implementation and assessment.
- Raise awareness and enhance technical capacity for the associated staff.
- Adapt any selected plan with the associated high-level state policy or plans.
- Try to give a regional vision to the selected plans (instead of just local one) by developing collaboration agreements between adjacent regions. It could be a collaborative agreement between the adjacent cities, countries, or states.
- Document the whole process from sourcing to engaging the locals, selecting the plans, developing the strategies and action plan, and implementation.
- Follow up the performance, monitor implementation, evaluate periodically, re-evaluating when necessary, and maintain long-term commitment for success.

2.1. Stakeholder Analysis

At the start of the project, it will soon be clear that a range of people/organizations should be involved in the planning process. The planning process means any effort from the planning to implementation to evaluate the GHG emission reduction process. However, it is significant to speciate the various stakeholders based on their level of input, involvement, level of ownership of the primary resources, and interest. The following will help classify potential stakeholders into two groups: Broad Community Groups and Targeted Technical Audience.

Broad Community Engagement

Community engagement is a crucial step in advancing the targeted GHG emission reduction. Individuals from every part of the society impact GHG reduction objectives. Corporate engagement so is a key step in planning and implementing a GHG reduction toolkit. This engagement will strengthen the results and guarantee its future implementation.

Targeted Technical Stakeholder Engagement

Technical project staff are engaged from associated organizations. They have to be led by a project manager and make the team. This team is responsible for undertaking the technical work and facilitating other stakeholders to make sure that the toolkit's design and implementation are implemented correctly.

A consultancy group also need to join such a technical project to undertake both quality assurance of the work and supervisory duties. The consultants can comprise city council staff as the core consultancy group and non-governmental organizations, private sectors, community members, startups, young professionals, and business representatives.

Special interest groups engage in the toolkit designing and implementation project by providing input from a particular interest group, who may not necessarily have the essential outreach to the broader community.

Leadership Group are those critically involved in the toolkit design and implementation project for decision making, fund allocation, and policymaking purposes. Figure 62 illustrates the main stakeholders in designing and implementing a GHG emission reduction toolkit.

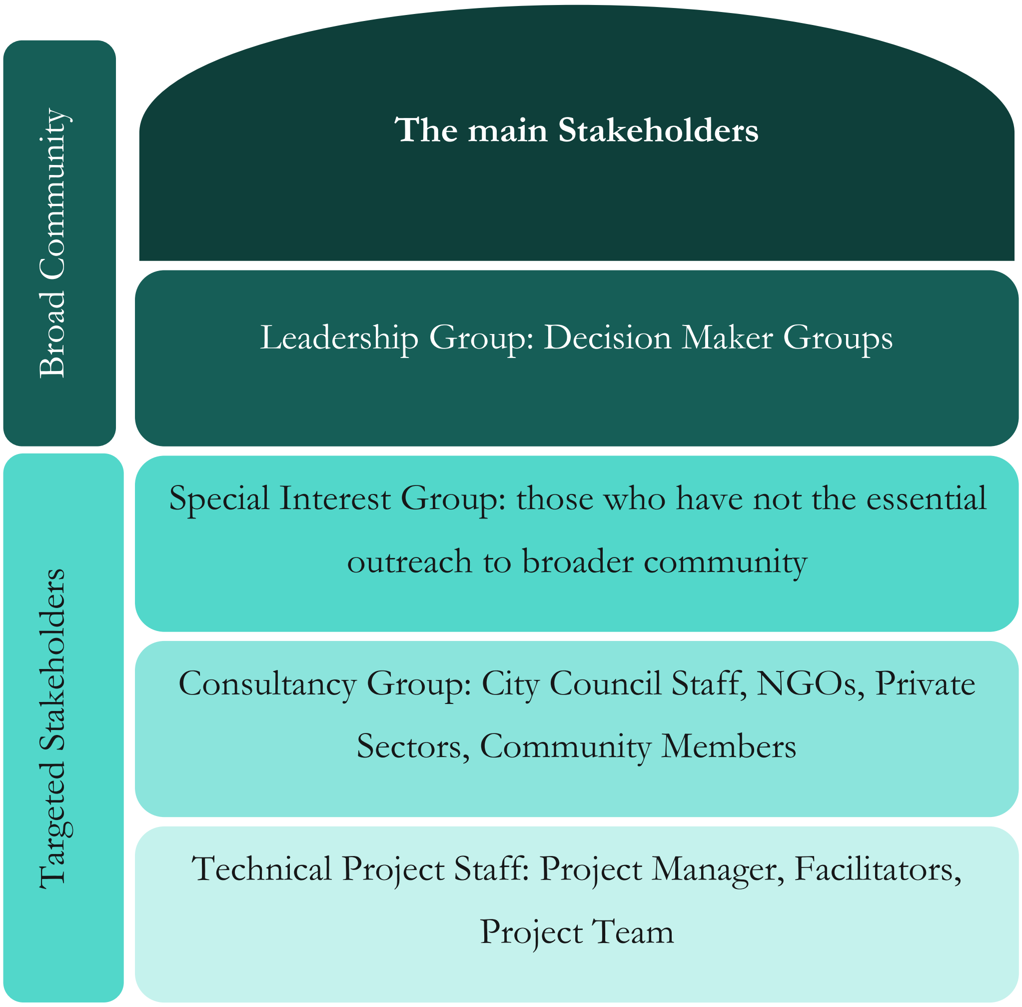


Figure 62: The main stakeholders in designing and implementing a GHG emission reduction toolkit

3. Delivering the Policy Framework

A key step in developing and implementing a GHG emission reduction toolkit is the Climate Change Policy Framework. In this stage, the value for emission saving is provided and presented to the local government. This value will then be applied in government economic appraisal. This will enable to embed climate change consideration into local and regional government decision-making process. There are several critical areas in which the GHG reduction policies need to be embedded, including: infrastructure, regulatory framework, goods, and service deliveries.

This climate change policy framework has to be accompanied by action plans explaining the responsibility of all parties with a closed time frame. The suggested action plans as annexes of this framework can be as follow:

1- Climate Change Adaptation Plan

This action plan, are those initiatives associated with building resilience among the community and thus, comprises some adaptation actions such as management solutions, market design, pricing laws, the mechanisms to move towards net-zero emissions, emission saving industry, healthcare industry, green insurance and sustainable financing.

2- Climate Change Mitigation Plan

This action plan is those associated with the mitigation plan among local communities, local governments, and all other stakeholders. These can include financing green industries, energy supply management, energy demand management, affordable renewable energies, green taxes on the goods and services, green entrepreneurship, carbon capturing industries, and so on.

Agencies will undertake additional policy investigation for sectors with significant opportunities and risks including (NSW Government, 2016):

- Energy productivity
- Fugitive emissions
- Primary industries emissions and adaptation
- Health and wellbeing

4. Development of a Monitoring and Evaluation Plan

All action proposed in the toolkit needs to be regularly reviewed consistent with local regulations and laws. Climate Change Policy Framework and the associated toolkit have to submit an annual report indicating the progress on the targeted goals and expenditure. This report makes the structure of a monitoring and evaluation plan.

Such a monitoring and evaluation plan needs to have a set of implementation and effectiveness indicators to evaluate the impact of proposed tools in climate change mitigation. These indicators need to be tracked and monitored over time and reported regularly. The report should reflect the long-term impacts of suggested toolkit's strategies/initiatives on the GHG emission and also their short-term effect on climate change. Thus, the report's nature needs to be results-based and focus on the expected outcomes of developing such a toolkit. Key elements of such a results-based report are presented in Figure 63.

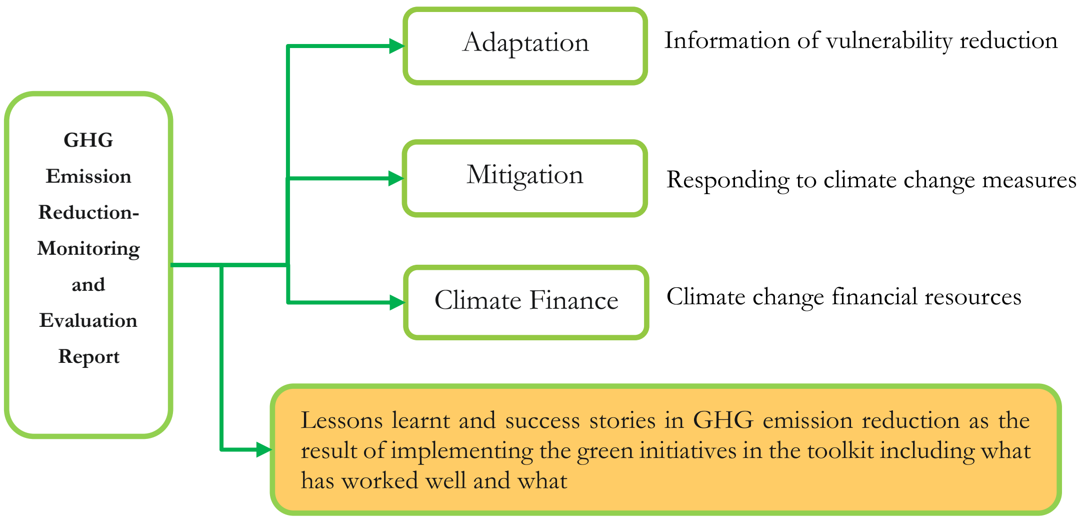


Figure 63: Key elements of the toolkits' monitoring and evaluation plan (Mabena, Cloete, Witi, & Molotsoane, 2018)

As this figure shows, the toolkit's report on GHG emission reduction can be classified into three groups: The adaptation-based results, the mitigation-based results, and the climate finance-results. The adaptation results are associated with society's vulnerability reduction. These address those tools targeting vulnerabilities and report how they are dealt with by implementing the toolkit. Some sample initiatives in this group include green infrastructure, behavioral changes, and green entrepreneurship.

Mitigation results are associated with responding to climate change. Results in line with reducing emissions and stabilizing the levels of heat-trapping greenhouse gases in the atmosphere are incorporated into this group. The associated for reducing sources of GHG emission (for example, the decreasing burning of fossil fuels for electricity, heat or transport) or strengthening the "sinks" that accumulate and store these gases are categorized in this group (NASA, 2020). As a tangible example from the toolkit, renewable energies, Hybrid/low-consumption vehicles, or increasing energy efficiency are welcomed here.

Climate finance results are associated with local, national, and regional financing from the public, private, governmental, and the various sources for funding aims to support mitigation and adaptation actions that will address global warming (United Nations Climate Change, 2020). It refers to making a consistent flow of finance towards low GHG emissions and building climate change resilience. Assessing progress in provision and mobilization of financial support needs to be transparent and results-base. It needs to be clear in the annual report against GHG toolkit implementation, which funds specifically is provided, to cover what area of GHG emission and what the measurable results were.

Conclusion

This PhD thesis is in line with Australia's national policy on reducing its greenhouse gas emissions 26-28% to the 2005 level. According to Australia's 2017 review of its climate change policy, the Australian Government is committed to deal with climate change, while it maintains a strong economy, affordable energy, and security for industries. This requires the introduction of new initiatives in existing technologies to reduce GHG emissions or even implement new technologies. Whatever the strategy, the final goal is to mitigate GHG emissions. This national target has been distributed among the different sectors and governmental bodies in Australia, requesting them to submit their action plans against climate change. This includes all the Australians city Councils and incorporates the Blacktown City Council as the Case study of this study.

Blacktown City is a modern bustling city of 48 residential suburbs, home to 350,000 people. This is the second largest local government area by population in New South Wales, Australia. With a population growth rate of 2.43% per annum, Blacktown will experience a massive boom in its industry, housing, and urban growth. Therefore, this will result in a drastic increase in GHG emissions because of urban growth, additional commuter vehicles, and a massive increase in energy demand. This might lead to the Council falling behind the national commitment to reduce greenhouse gas emissions. However, Blacktown City Council has adopted the Blacktown Climate Change Action and Adaptation Plan in 2011 and the revised version of the plan released in 2018, which is the Blacktown Response to Climate Change Policy.

Under this policy, the Council has committed to achieve net-zero emissions from electricity, fuel, and gas by 2030, adopt best practices to mitigate the impacts of urban heat in its operations and increase tree canopy cover and vegetation in streets and reserves. These specific policies, with their associated action plans, can ensure that GHG emissions will not increase in the Council's LGA, and the Council will achieve net-zero emission if all the plans are executed.

As the part of the Council commitment to reduce its greenhouse gas emissions, this research study is a collaborative effort between the Council and the Western Sydney University. In this project, the council was provided the candidate with an office, possibility of interviewing with the related authorities, the required data software including Arcmap, the raw shapefiles and sometimes with the vehicles. All other phases of the research study, including literature review, finding the research gap, discovering the problem, analyzing the shapefiles, making the model and interpreting it was undertaken by the candidate. The related authorities from both sides have signed a research collaboration agreement, which is a local university's initiative of dealing with local problems. This research agreement is unique as it opens the door to other local Councils to collaborate with the university. The other side of this agreement is Blacktown City Council, which can improve its body of knowledge through a comprehensive investigation of its available tools towards greenhouse gas mitigation. This research study has developed a toolkit for reducing the Council's GHG emission.

The main aim of this research project was to prepare a GHG emission reduction toolkit for Blacktown City Council to mitigate its GHG emissions at the city level. For this purpose, four key areas have been identified and were examined in this toolkit, including:

1. GHG emission reduction toolkit in transportation
2. GHG emission reduction toolkit in waste management
3. GHG emission reduction toolkit in urban land use
4. GHG emission reduction toolkit in energy management

These four mentioned areas are the main episodes of the toolkit, which suggest the potential tactics for GHG emission reduction at the city level. They also are a beneficial instrument for policymakers and city planners to lead their municipal level programs accordingly. The four mentioned areas are the major GHG emitters in a city, as explained in section 5 of chapter 2. The other objective of this study was to propose the GHG emission reduction potential in each part and to examine a single tool for each episode in Blacktown City. Piloting a tool from a comprehensive toolkit and quantifying its GHG emission abatement potential, would make a way forward for the other instruments to be quantified and calibrated for each region. This research study undertook 3 different approaches:

1- To assist a local council in a policymaking process. In this approach, this study puts a step forward to link academic research with a real problem on the field, highlighting the role of a local university in covering up a real practical issue on the ground.

- The main achievement of the study in this approach was making a connection between Western Sydney University to a local council and signing a bilateral agreement between two parties. It was an innovation in its kind in the university to sign an agreement at the higher degree level to deal with the research requirements of a local council. Also, it was a new approach for the Council to making use of a higher degree research study and apply it in their policymaking process.

- Some benefits in making such an agreement are saving the data-gathering process for baseline studies, facilitating the interview processes, and making use of the university's academic library and free databases. Finally, it keeps the data processing time and allocates more time and resources for analytical purposes.

- Although there are so many benefits to making such an agreement, there would be some limitations too. The research objectives will usually be limited to those of the Council's, and the case studies will also be the same. The opportunities for piloting the project will be restricted to geographical regions of the local Council, and the objectives should be in line with their current policy and strategic plan.

2- To fill the research gap in the body of knowledge, to present a comprehensive toolkit for lowering GHG emission reduction potential at the city level. My studies show; although there are scattered researches to alleviate GHG emission at a city level, there isn't any universal study to put them all together in an integrated toolkit. This issue caused by a local council such as Blacktown in Australia doesn't have access to a comprehensive, integrated toolkit representing the potentials of GHG emission reduction.

- The main achievement of this study in this approach was to develop a comprehensive toolkit covering almost all sources of GHG emission at the city level in one place. This is a worthwhile achievement since it was drowned up on a 20 years literature review from 2000-2020. The associated toolkits, standards and mechanisms were investigated during the period, presenting the final result in the form of a toolkit.

- The main benefit of having such a toolkit is to deal with the problem of climate change at the urban scale, on the smallest size. There are many standards for GHG emission reduction at a city level, as cited in chapter 2, but all of them proposed generic strategies for alleviating GHG emission at this scale. This study's results can be considered as an amendment to those mentioned standards in helping city planners in their long-term budgeting and resource planning.

- The main limitation of the study in this approach was to estimate the abatement potential of the proposed tools. There is an ambiguity about whether a suggested abatement potential in a region can be extrapolated for the others or not? The answer is not straight forward. It is tried to make use of multiple resources to cover up this query; still, the question remains. This is because the GHG emission reduction toolkit is in its infancy, and more literature and research should be undertaken in this field.

3- To pilot three introduced tools of the most significant sources of GHG emission at a city level. It was impossible to examine all the suggested tools for decreasing GHG emission and regionally calibrate them in a single study. Instead, this research chose one initiative in each sector to test the proposed mechanisms and to quantify them with the relative abatement potential.

- The main achievement of this study in this approach was to quantify the abatement potential of three suggested tools in the toolkit. It was worthwhile for the Council to know that in which specific tool it has to focus on and what is the abatement potential of each.

- The main benefit of quantifying this toolkit's reduction potential is to assist the Council in prioritizing its climate change strategies and action plans. Measuring the GHG emission reduction of the suggested tools can help a local council to finance the most cost-effective means with a short-term payback period.

- The main challenge in quantifying the toolkit is the cost and time-consuming process of measuring the abatement potential for most of the tools. Quantification of three tools took over a year in this study, and should it replicate for the whole toolkit; it certainly takes a remarkable time and effort.

Chapter 1 of this thesis is the Introduction. This chapter introduced climate change as the most influential global issue of the century, impacting human survival, and development. This chapter went on to describe global action against climate change, focusing on the Paris Agreement on Climate Change and the United Nations Sustainable Development Goals. It introduced articles 2, 4, 5, 6, 13, 21 from the Paris agreement and describes targets 1.5, 7.1, 7.2, 7.3, 13.1, 13.3 from the United Nations Sustainable Development Goals. These are international goals and targets, which can justify the importance of this research study.

The chapter then introduced Australia's National and State policies to mitigate GHG emissions. In particular, it details Australia's 2017 Review of Climate Change Policies, NSW Climate Change Policy Framework and Blacktown- Responding to Climate Change Policy. These are national and local high-level documents that define this research study.

In ***Chapter 2***, had a look at the international GHG emission reduction toolkits at the neighborhood level and focused on their main criteria. In particular, the main criteria of a GHG emission reduction toolkit was extracted in this chapter, compared and the main and common factors of these international systems was selected for this study. The results of this comparison showed that community, resources, and ecology are the top three sustainability aspects applied in 18, 17, and 16 carbon reduction toolkits, respectively, out of 20. These three aspects earned almost the same importance in the systems around the world. With a review of these three selected sustainability aspects, it was found that they cover the three pillars of sustainability. Community returns to society, resources indirectly return to economy, and ecology refers to the environment. However, after affecting the sustainability themes by their weighting in each system, the differences among the aspects were removed and they became closer to each other. In this new set, ecology, energy, transportation, resources, and economy received the highest rate and incredibly, community dropped to a lower rate of importance.

Chapter 3 introduced Blacktown City Council as the Case study of this study. First, it explained the Case study, its population, history, and background. Then, it introduced the four main Council's policies and plans to adapt climate change and mitigate it, including: Responding to Climate Change Policy, Integrated Transportation Management Plan, Urban Forest Policy, and Carbon Accounting Method. In Blacktown-Responding to Climate

Change Policy, policy commitment 1, 2, 3 have been introduced and their relationships with this research study have been extracted. From the Integrated Transportation Management Plan, it was discussed how the Council will move away from reliance on car use towards more sustainable transport modes, such as walking, cycling and public transport. The Council introduced the Urban Forest Policy Objective No. 1, which committed to develop long-term strategies to increase the quantity and quality of the Council's tree population on the streets and in parks. From the Carbon Accounting Method, three scopes that the Council needs to report under have been described.

Chapter 4 introduced the applied methodologies in the study. Firstly, it explained the necessity of a GHG emission reduction toolkit in an urban scale, then the procedure of structuring the kit and its main elements are introduced. Finally, a snapshot on the applied methods for piloting the tools were presented and their linkage illustrated using a road map of applied methodologies.

Chapter 5 focused on the impact of route optimization of heavy vehicles on GHG mitigation. In particular, it quantified the distance driven by the different types of heavy vehicles in the optimized route and compared to their regular routes. The purpose of this comparison was to evaluate the impact of route optimization of heavy vehicles on fuel consumption and GHG emissions. Two types of Council trucks were selected: 1) A garbage truck with almost fixed daily destinations and routes; and 2) A tree maintenance truck with the various daily missions and destinations.

The results of this research showed that the total savings in kilometers traveled per month for the tree maintenance truck was 431 km, which was equal to a 60.38% decrease in kilometers travelled in the optimized path versus the actual one. In addition, the simulated model showed that the actual fuel used was 380 liters/month; however, the simulated one was 146 liter/month, which is a 62% decrease in fuel use. In addition, the total actual GHG emissions were around 1.034 tons of carbon dioxide equivalent per month versus 0.397 tCO_2-e in the optimized route. This showed a 62% drop in GHG emissions, which is close to the savings in fuel consumption and kilometers traveled per month.

The results of the study on the waste collector trucks showed that using the optimized route could save around 10 kilometers per day. When multiplying this result by the 21 working days per month on average, the total saving in kilometers traveled per month would be around 210 km/m. In addition, using the optimized route, 183 L of fuel per month can be saved, which is an 11% reduction in fuel usage. The total reduction in GHG emissions would be 0.456 tons per month, which is around 10% of the average GHG emitted by this type of truck.

Chapter 6 investigated some solutions for reducing GHG emissions from the waste sector. The main purpose of this chapter was to measure proportions of waste categories in public facilities, identify potential opportunities for general waste reduction, and quantify the GHG emissions reduction that might be achieved through each opportunity. For this purpose, two public facilities owned by Blacktown City Council were selected: Max Webber Library and Blacktown Aquatic Centre. Both are large examples of their kind and represent similar facilities.

Waste audits were conducted at these two facilities, and the different categories of waste were separated and measured. The results showed that only 35% (769 kg/y) of the waste in Blacktown Aquatic Centre and 25% (278 kg/y) at Max Webber Library were general waste. The remainder was either recyclable or compostable. The proposed scenarios for reducing the general waste stream at these two centers and reducing the associated GHG emissions are as follows:

- Removing coffee cups from the general waste stream by introducing small coffee cup bins and partnering with the Simply Cups initiative in Australia. This would offer a potential GHG emission reduction of 0.275 tCO2-etCO2e/y for 10 similar public facilities at Blacktown City.
- Removing plastic bags from the general waste stream by introducing plastic bag bins and joining with the REDCycle program, which would offer potential waste reduction of 1.10 ton/y for 10 similar public facilities at Blacktown City.
- Removing food from the waste stream by providing access to on-site worm farms in each center, offering potential GHG emission reduction of 0.161 ton/y and potential waste reduction of 839 kg/y.

The main aim of ***Chapter 7*** was to compare the difference street cooling strategies at Kent Street, Blacktown City, analyze them, and propose the best set of UHI mitigation scenario.

Considering that any particular region has its own microclimate processes, including wind speed, sun and shadow hours, natural green cover, the average building height and ets, a unique suggestion, which is suitable for any region cannot be applied, and it is necessary to propose a customized set of UHI mitigation strategies. Using the ENVI-met microclimate processor, this chapter combined all various microclimate variables, considering the specific climate of the studied zone to identify the most suitable strategy for cooling down the sensible temperature at street level. The list of final proposed cooling strategies is as follows:

- Replacing the loamy soil with the grass in the North-East corner of the studied region.
- Replacing the asphalt parking areas in the North-East and South-East sides of the region with light concrete pavement with the higher albedo rate.
- Planting tall trees at the North-East side of the street to provide shade during the day for the whole length of the street. This will reduce air temperature by up to 3°C and the surface temperature by up to 11°C in the afternoon of a hot summer day.
- Planting short trees in the South-West side of the street to provide shade for the southern pavement. This will reduce the sensible heat flux up to 382 W/m2 for those traveling alongside the street.
- In addition, the green canopy strategy mostly reduces the daytime temperature; however, the cool pavement scenario reduces both daytime and nighttime temperature.

By applying all these street cooling strategies, the air temperature at the hottest time of a sample summer day, can be reduced by up to 3°C, the surface temperature can be reduced by up to 20°C, the mean radiant temperature by up to 30°C, and the sensible heat flux by up to 382 W/m2.

Chapter 8 gathered a comprehensive list of the council's energy efficiency initiatives, analyzed and compared them.

Among all these measures, the installation of energy saving units was the most cost-efficient measure, as its cost per tonne of GHG reduction ranged from $132 to $165 for 350 and $450 KvA energy saving units, respectively. The next cost-efficient action was retrofitting the dog kennel heaters to higher efficiency units, replacement of the electric hot water systems with solar hot water system and affixing the variable speed drives to pool motors.

In addition, the installation of a soft starter energy efficient pump for the wave pool has been the most expensive measure implemented by the Blacktown City Council, as its cost per tonne of GHG reduction is $6875. The least cost-efficient measure was the replacement of South Wing air conditioning, upgrading of outdated and inefficient kitchen equipment, and the installation of energy meters at major sites.

Considering payback times of the measures, the installation of 350 KvA energy saving units, with just one-year payback time has earned the first rank among the 22 measures followed by affixing variable speed drivers to pool motors having just one-year payback period, with has earned the second lowest payback time among the measures.

On the other hand, replacement of East Wing air conditioning, with 37 years of payback time was the longest lasting payback measure of the Council. Replacement of the South Wing air conditioning, followed by the upgrade of outdated and inefficient kitchen equipment, has the next longest payback time with 33.4 years and 20 years, respectively.

Chapter 9 as the heart of this thesis, introduced the GHG emission reduction toolkit in four pre-defined categories. This chapter summarized the carbon reduction strategies of other chapters, and takes a step forward to present a comprehensive GHG mitigation toolkit by reviewing the associated literature.

Chapter 10 presented the key recommendations for using the introduced toolkit in chapter 9. This chapter introduced the international implications of this research study and its applicability in other regions. In addition, it explained the significance of community engagement in the toolkit's planning and implementation process. Also, it described the process toward delivering a policy framework for execution of the toolkit and presents a monitoring and evaluation plan for assessing the toolkit's implementation process.

Possible Further Development of this Research Study

This research study has taken a step forward to develop a GHG emission reduction toolkit at the urban scale. However, this area of the study is still in its infancy period; there is a vast opportunity for improvement in this field. Nations of the world have agreed to limit global warming to 2 degrees C above pre-industrial levels (Erickson & Tempest, 2014). Doing so will require staying within a strict "carbon budget". So far, national effort to mitigate emission, have not been sufficient to put the world in a safe pathway consistent with this target. Therefore, new initiatives are required to enhance and extend the ambition to cover the gap between the current trend and our 2-degree Celsius target. In this research study, it is showed that cities have a vital role to play in deepening the goal of global warming. Urban areas have a unique and robust impact on policy levers, such as urban planning and public transportation. This is where their role becomes critical in mitigating GHG emission and reducing the cost of further mitigation. Here in this study, the potential initiatives for GHG reduction are proposed. National policymakers may apply this toolkit to assist and strengthen their regional GHG emission reduction programs.

An urban scale action scenario is presented that investigates how urban level plans and programs may help reduce global warming in the next decades. Few evaluations of urban level GHG reduction have yet been undertaken, and there were no universal, consistent guidelines in this regard. Existing assessment vary substantially in what we consider as "city" in terms of emission scopes and abatement potential. But it is not the final step. We are still at the beginning of a long way to be consistent in our global goal of 2 degrees Celsius. More and more researches need to be carried on, and more stakeholders are to be engaged. Here the results of a council in Australia is presented, its role in GHG mitigation and how it can contribute to the national and international targets. It was just an example; the whole picture is yet to be accomplished.

There is a wide range of other players in the game of GHG emission reduction. Everyone has a role to play. City councils are one of them, but what about the other governmental bodies in the boundary of a city? Water management organizations, for instance, their task is as crucial as city councils. Wastewater management and its role in GHG reduction are an example. Capturing nitrogen and carbon in swages is another example. Increasing the efficiency of transfer lines and optimized distribution are just some samples of what can be investigated in the water management industry.

Other urban infrastructures would be another major area to focus on. For instance, telecommunication technology, such as how the more efficient technologies in the boundary of a city contribute to global warming, can be a point of focus. What about satellite ICT technologies and their impact on GHG emissions? Could this newly-introduced engineering systems reduce or eliminate society's need for transportation? Are we really connected using telecom technologies, and there is no need for more fossil fuel consumption? These can be the highlights of another novel toolkit to be added to the literature.

I want to go ahead for a more comprehensive toolkit to a life-cycle-inclusive one. There is definitely a lack of literature in this regard. Most of the available global standards consider the functional time of an activity, a function, or a structure. This is absolutely not sufficient. For instance, if we proposed to replace the fluorescent lamps with the LED ones in the buildings, are we considering the whole process of manufacturing, distribution, transportation, and installation in a long-term period? Is this replacement really cost-effective in terms of GHG emission?

There are not only some areas to work in the infrastructure industry, but human behavior as well. All we do as city planners finally needs to be transferred and implemented by society. What is the role of community and its smallest component, human? We need to change our behavior and our expectation from the urban-level services. We need to be adopted to a more local lifestyle to build a local community with the local services and providers. To what extent are we ready to justify ourselves to this new low-carbon lifestyle? This can be a subject of a new municipal level toolkit for reducing GHG emission.

It is not all about developing a GHG reduction toolkit, but about the assessment toolkit as well. There is absolutely a lack of a comprehensive assessment toolkit for evaluating the effects of abatement initiatives. To what extent they are valid and how they are periodized in a specific geographical region?

The time boundary could be another source for improving an existing GHG reduction toolkit. There are different levels of policymaking process, including long-term, medium-term, and short-term. The time frame can be added to the toolkit to make a comprehensive set of the new initiatives for 2030, 2050, and 2070, for instance. Nature and the extent of the introduced initiatives are differed as well considering increased population, enhanced technologies, and the warmer world.

Finally, the toolkit scale can be another source of new methodological research in this field. This study developed a GHG reduction kit at a city level, but it can be developed at the neighborhood, regional, national, and international levels too. Here a medium-scale set of tools is investigated, but its nature will certainly be different at the other scale, which provides an open window for a more in-depth investigation.

These were just some novel ideas for further development of such an urban-scale toolkit; however, the nature and the extent of the new literature are not limited to them. The severe, serious problem of global warming caused during a century, entails communal, inter-sectoral solutions. Although the essence and degree of the problem are horrific, making use of the upcoming applied science and new literature in this field, would unlock the issue and provide new generations with a better world.

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Attachment 1

The research collaboration agreement

2017

Research Collaboration Agreement

WESTERN SYDNEY UNIVERSITY

Blacktown City Council

RESEARCH AGREEMENT

THIS AGREEMENT effective April the 3rd, 2017 by October the 3rd, 2018 and, between BLACKTOWN CITY COUNCIL (hereinafter "Sponsor") and the WESTERN SYDNEY UNIVERSITY, a non-profit educational institution (hereinafter "University").

WHEREAS, the research program contemplated by this Agreement is of mutual interest and benefit to University and to Sponsor, will further the instructional and research objectives of University in a manner consistent with its status as a non-profit, tax-exempt, educational institution, and may derive benefits for both Sponsor and University through inventions, improvements, or discoveries;

NOW, THEREFORE, in consideration of the promises and mutual covenants herein contained, the parties hereto agree to the following:

ARTICLE 1 - DEFINITIONS

As used herein, the following terms shall have the following meanings:

1.1. "Project" shall mean the research project described in Research Proposal as the attachment 1 of this agreement.

1.2. "Contract Period" is from April the 3rd, 2017, by October the 3rd, 2018, unless earlier terminated pursuant to this Agreement.

1.3. "Joint Intellectual Property" shall mean individually and collectively all inventions, improvements or discoveries which are made jointly by one or more employees of Sponsor and one or more employees of University in performance of the Project during Contract Period.

1.4. "Researcher" is a PhD student who works on this project as her PhD research project.

ARTICLE 2 - REPORTS AND CONFERENCES

2.1. Written program reports shall be provided by University to Sponsor periodically and a final report shall be submitted by University at the conclusion of the Contract Period.

2.2. During the term of this Agreement, representatives of University may meet with representatives of Sponsor at times and places mutually agreed upon to discuss the progress and results as well as ongoing plans, or changes therein, of Project to be performed hereunder.

ARTICLE 3 - COSTS, BILLINGS, AND OTHER SUPPORT

3.1. Sponsor offers no payment for the University upon this agreement. Rather, the Researcher will benefit from the ARC (Australian Research Council) funding.

3.2. Sponsor provides the Researcher with a workplace and a computer and access to internet for a minimum of three days per week.

3.3. Sponsor provides researcher with all the necessary data except confidential ones in accordance with the requirements of the Project.

3.4. Where necessary, Sponsor provide Researcher with a vehicle to conduct field survey and collect the essential data for undertaking the Project.

ARTICLE 4 - PUBLICATIONS

Sponsor recognizes that under University policy, the results of University Project must be available for publication and agrees that researcher engaged in Project shall be permitted to present at symposia, national, or regional professional meetings, and to publish in journals, theses or dissertations, or otherwise of their own choosing, methods and results of Project, provided, however, that Sponsor shall have been furnished copies of any proposed publication or presentation for review at least thirty (30) days in advance of the submission of such proposed publication or presentation to a journal, editor, or other third party. Sponsor shall have thirty (30) days after receipt of said copies, to object to such proposed presentation or proposed publication because there is patentable subject matter that needs protection or because Confidential Information disclosed. In the event that Sponsor makes such objection, said Researcher shall refrain from making such publication or presentation for a maximum of one hundred twenty (120) days from date of receipt of such objection in order for University to file patent application. University will comply with Sponsor's request to delete or modify Confidential Information*

ARTICLE 5 - INTELLECTUAL PROPERTY

All rights and title to Joint Intellectual Property shall be jointly owned by Sponsor and University.

ARTICLE 6- TERM AND TERMINATION

6.1. This Agreement shall become effective upon the date first written above and shall continue in effect for the full duration of the Contract Period. The parties hereto may, however, extend the term of this Agreement for additional periods as desired under mutually agreeable terms and conditions.

6.2. No termination of this Agreement, however effectuated, shall release the parties from their rights and obligations accrued prior to the effective date of termination.

ARTICLE 7 - INSURANCE AND INDEMNIFICATION

7.1. University warrants and represents that University has researcher and employees while acting within the scope of the Project by University. University has no liability insurance policy as such that can extend protection to any other person.

7.2. Each party hereby assumes any and all risks of personal injury and property damage attributable to the negligent acts or omissions of that party and the officers, employees, and agents thereof.

ARTICLE 8- AGREEMENT MODIFICATION

Any agreement to change the terms of this Agreement in any way shall be valid only if the change is made in writing and approved by mutual agreement of authorized representatives of the parties hereto.

ARTICLE 9 - CONFIDENTIALITY

University agrees to use the proprietary information and data acquired from Sponsor and identified as such at the time of disclosure ("Confidential Information") only in performing the services of this Agreement and not to disclose to any third party any such Confidential Information during and for a period of five (5) years from the date of disclosure.

University	**Sponsor**
By:	**By:**
Name: Associate Professor Sergiy Kharkivskiy	**Name:** Vanessa Parkes
Title: Higher Degree Research Director	**Title:** Manger Environment
By:	**By:**
Name: Vivian Tam	**Name:** Donna Wallace
Title: Associate Professor	**Title:** Acting Team Leader Environment
By:	**By:**
Name: Hoda Karimipour	**Name:** Helen Burnie
Title: Researcher	**Title:** Acting Senior Environmental Officer

6.2. No termination of this Agreement, however effectuated, shall release the parties from their rights and obligations accrued prior to the effective date of termination.

ARTICLE 7 - INSURANCE AND INDEMNIFICATION

7.1. The University provides full insurance cover for the Researcher and University employees while they act within the scope of the Project.

7.2. Each party hereby assumes any and all risks of personal injury and property damage attributable to the negligent acts or omissions of that party and the officers, employees, and agents thereof.

ARTICLE 8- AGREEMENT MODIFICATION

Any agreement to change the terms of this Agreement in any way shall be valid only if the change is made in writing and approved by mutual agreement of authorized representatives of the parties hereto.

ARTICLE 9 - CONFIDENTIALITY

The University agrees to use the proprietary information and data acquired from the Sponsor only in performing the services of this Agreement, and for no other purpose during the Contract Period or after.

University

By: [redacted]

Name: Associate Professor Sergiy Kharkivskiy

Title: Higher Degree Research Director

By: [redacted]

Nam[redacted]

Title: Associate Professor

By: [redacted]

Name: Hoda Karimipour

Title: Researcher

Sponsor

By: [redacted]

Nam[redacted]

Title: Manager Environment

By[redacted]

Name: Donna Wallace

Title: Acting Team Leader Environmental Services

By: [redacted]

Name: Helen Burnie

Title: Acting Senior Environment Officer

Attachment 2

Research project proposal

RESEARCH PROJECT PROPOSAL

The Carbon Footprint Reduction Toolkit for Blacktown City Council (On Selected Activities)

1. Background and problem statement

Climate change has become a global issue influencing human survival and development and urban carbon emissions are the main factor contributing to climate change (Ganaut, 2011). Australia has a naturally highly emissions-intensive economy, currently, with far higher emissions per capita than any other developed country (Wang et al., 2016). Most other developed countries now have falling or steady emissions; however, largely because of economic development, Australia's emissions continue to increase (Wang et al., 2016).

However, under the Paris Agreement, Australia has committed to reduce emissions by 26 to 28% below 2005 levels by 2030. This will see emissions per capita halved and the emissions intensity of the economy fall by around 65%. Across a range of indicators, this target is in step with other major developed countries, such as the United States, the European Union, Canada, and New Zealand, and on a per capita basis, among the highest of the major economies. In 2017, the Australian Government will review its climate policies and consider a potential long-term emissions reduction goal for beyond 2030 (Australian Government, 2017).

Australia's 2030 target builds on its 2020 target of 5% below 2000 levels, which it is on track to beat. Australia's official projections from December 2016 estimate it will over-achieve this target by 224 million tons of carbon dioxide equivalent (Mt CO_2-e). This follows on from the Kyoto Protocol first commitment period (2008–2012) target, which Australia over-achieved by 128 Mt CO_2-e (Australian Government, 2016). Since a considerable part of Australia's emission comes from its commercial, residential, and transportation sector (Infrastructure Australia, 2010), it is clear that the most important part of Australian emission reduction must focus on its cities.

Blacktown City is a modern bustling city of 48 residential suburbs, home to 340,000 people. This makes it the second largest city by population in New South Wales. With population growth of 1.85% per year (id the population experts, 2016), Blacktown continues to face huge environmental problems, such as land use changes, urban heat islands, and air and water pollution. To tackle these issues, in 2011, the Council adopted the Blacktown Climate Change Action and Adaptation Plan (BCCAAP), which outlines Blacktown City Council's commitment to addressing climate change for the benefit of current and future generations. It provides a snapshot of the achievements to date and highlights the opportunities for reducing carbon emissions further. The BCCAAP also identifies areas of vulnerability to climate change and recommends actions to assist in adapting to the impacts of climate change in Blacktown City (Blacktown City Council, 2015a). However, this plan needs to be updated to reflect the Council's increased commitment to reducing emissions and being a more sustainable city. For this, the potential areas of carbon abatement should be identified as both carbon emission sources and carbon dioxide sinks.

1.1. Council's current carbon accounting

Currently, the Council only accounts for the carbon emissions from its energy and fuel use. The Council gives consultant Planet Footprint access to its electricity and gas bills and fuel use data. Planet Footprint calculates the related greenhouse gas emissions for Scope 1 and Scope 2. Scope 1 emissions are released directly into the atmosphere as the result of an activity, or series of activities at the facility level (including transport that goes offsite) (Clean Energy Regulator, 2016). Examples of Council's Scope 1 emissions are those from burning diesel fuel in trucks and the onsite burning of gas for energy at the leisure centers. Scope 2 emissions are from the indirect consumption of energy. The main example of Council's Scope 2 emissions is the use of grid electricity generated mainly by power stations burning coal.

Planet Footprint also calculates the Council's Scope 3 emissions relating to its electricity, gas, and fuel use. Scope 3 emissions are from indirect, largely supply chain activities (other than Scope 2 electricity emissions) from sources not owned or controlled by that facility's business (Clean Energy Regulator, 2016). Examples of Council's Scope 3 emissions are those from extraction and production of purchased materials, transportation of purchased fuels, and operational waste.

According to Figure 1, 41% of Council's emissions come from street lighting, 38% from operational electricity, 16% from fuel consumption, and 4% from other usage. This proves the importance of the first three fields in improving the Council's carbon abatement.

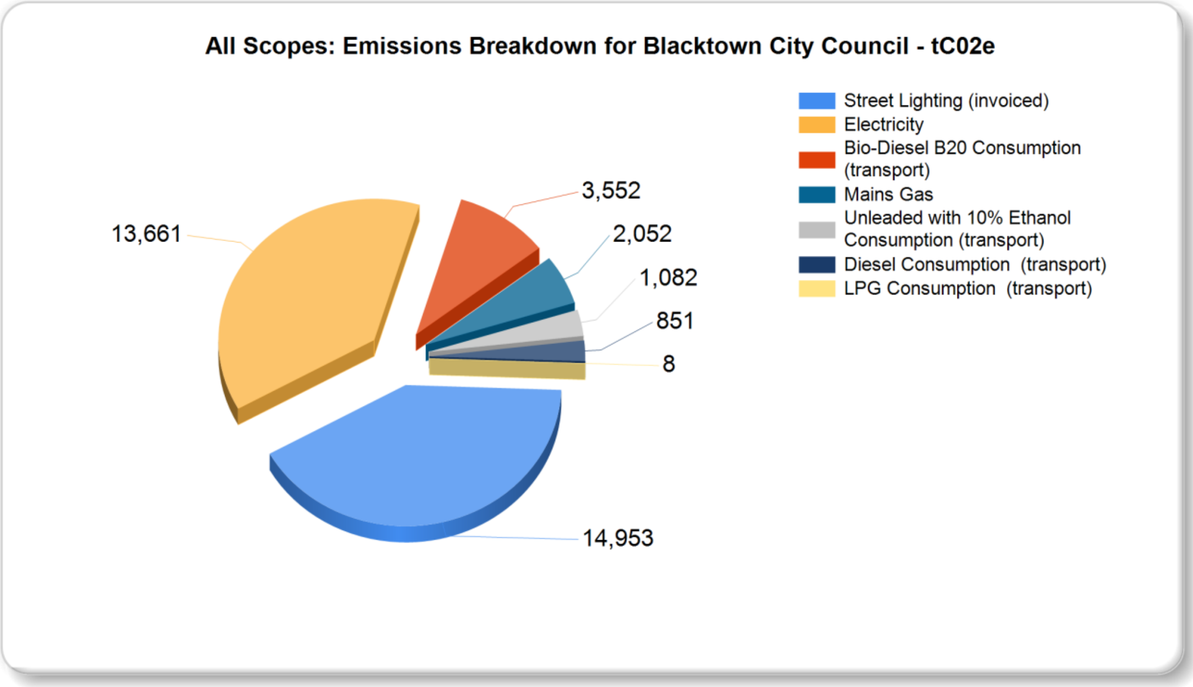

Figure 1: Council's Energy and fuel greenhouse gases 2015-16

1.2. GHG emissions from the Council's fleet

Figure 1 shows the Council's 2015-16 net emissions from energy and fuel consumption, as calculated by Planet Footprint (Planet Footprint, 2017). These emissions totaled 36,159 t/CO2e and included Scope 3 (supply chain) emissions for the Council's energy and fuel, for example, through electricity transmission loss and transporting the fuels to be used by Council. Despite the Council's operational growth, the steps taken to reduce emissions have limited this figure to a small increase on the 34,470 t/CO2e emitted in the baseline year 2005-6 (Planet Footprint, 2017).

Transport was responsible for 16% of the Council's emissions; related fuel included unleaded petrol, diesel, biofuel, and LPG.

1.3. GHG emissions from waste

In 2009, McGregor Environmental Services conducted a waste audit of a representative sample of all of the Council's building types, for an indication of the amounts and types of waste produced by major Council buildings. This audit made recommendations to improve recycling and resource recovery at the Council's facilities. According to this survey, about 30% of Council's operational waste is compostable, 40% recyclable and almost 30% went to landfills. Figure 2 shows the Garbage Stream at a childcare center of the Council. The study recommended opportunities to improve the waste management system in the

Council, including developing worm farms, placing some recyclable bins in the pools, and other assets or capacity development for better use, on-site composting, and so on. However, this study is old and it needs to be updated.

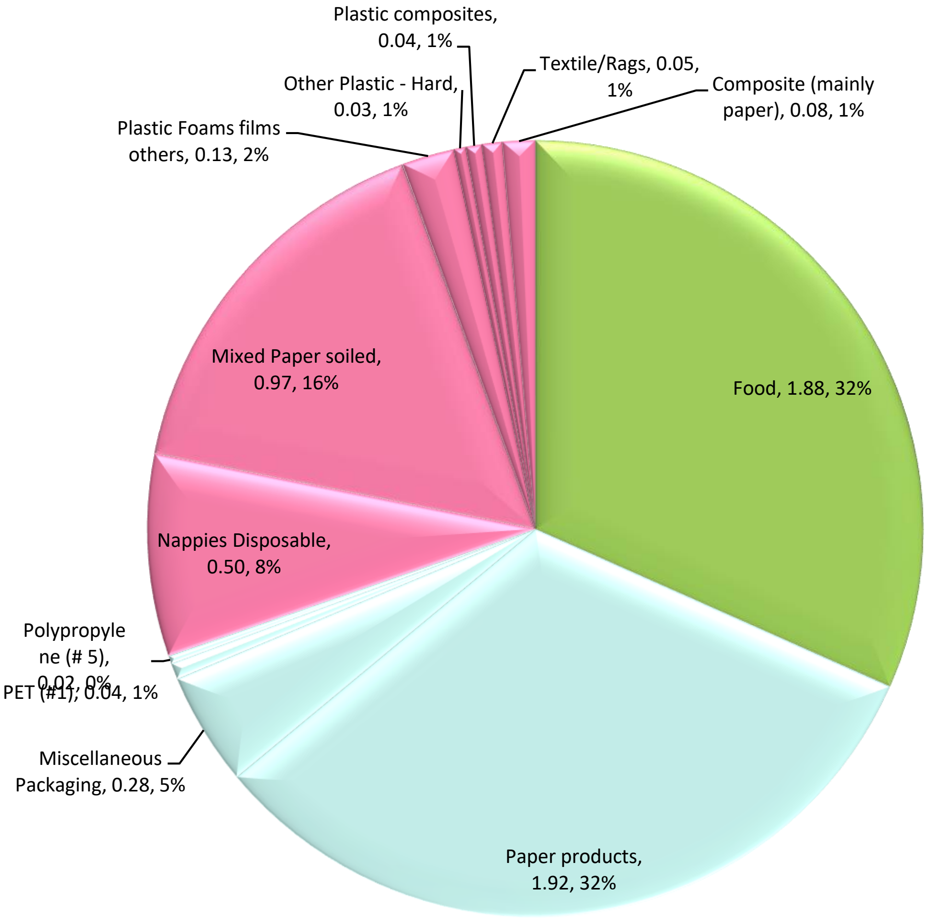

Figure 2: Garbage Stream at Quakers Hill Childcare Centre (Kg)

1.4. Previous and current carbon sequestration via Green Planting

Natural processes such as erosion and sedimentation have always shaped the land; however, these processes have been vastly accelerated by certain types of human land use. In populated areas, such as the Blacktown LGA, land use by humans has significant impacts on land characteristics. Competition exists among a range of human land uses, including urban expansion, transport, open space, industry and agriculture. As the population continues to grow, urban expansion will persist as the most significant pressure on land in the Blacktown LGA (Blacktown City Council, 2011).

Biodiversity is important for nutrient cycling, soil formation, and pollination. Several issues affect biodiversity in the Blacktown LGA. These include the degradation and loss of terrestrial ecosystems, loss of terrestrial species diversity, and native vegetation clearing. These issues are attributable to several factors, including land clearing for urban development and infrastructure, degradation of habitat through fragmentation, loss of habitat, edge effects, isolation, and fire, invasion by feral weeds and animals, water pollution, sedimentation, and increased nutrient loads in waterways.

However, to conserve its biodiversity and combat land use change, the Council undertakes several bush regeneration projects funded through grant programs, Council's Works Improvement Program, and maintenance budgets. A Regeneration and Re-vegetation Strategy has been developed. It includes targets for monitoring the number of indigenous species to guide biodiversity conservation in the LGA. Figure 2 shows the number of trees and shrubs planted by the Council and volunteers under Council programs to reduce GHG emissions and combat urban heat island effects (Blacktown City Council, 2011).

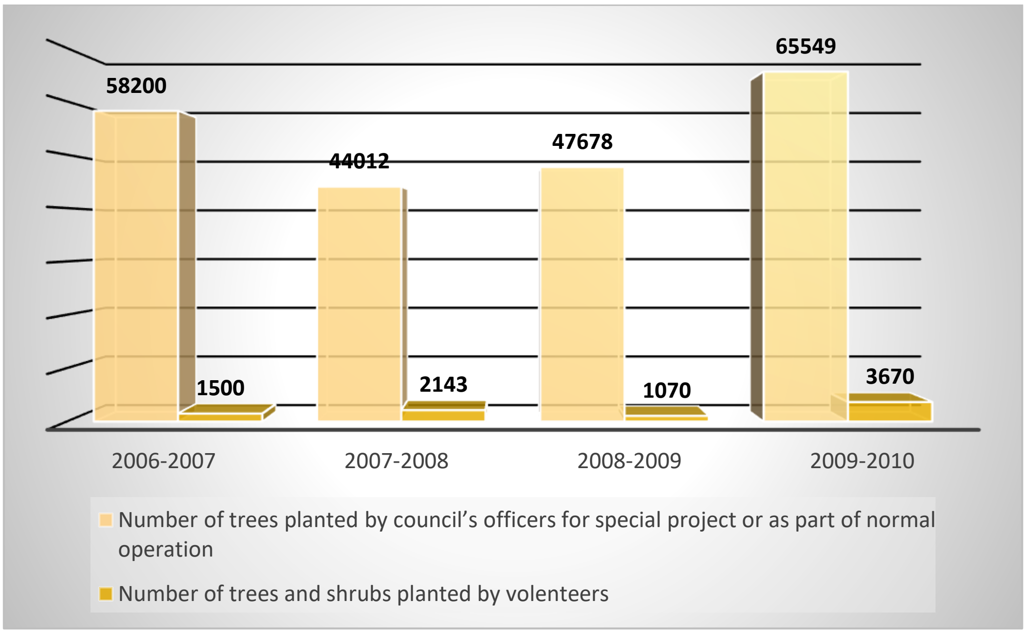

Figure 2: Number of trees and shrubs planted by the Council and volunteer groups

4. **Project goals and key deliverables**

The Council aims to develop and update BCCAAP to implement it from 2018 to 2030. The proposed research will provide updated data on fleet, operational waste, and carbon sequestration opportunities. A separate project is working to reduce the major source of Blacktown City Council's operational carbon emissions, electricity use. This research proposes to investigate the potential areas of carbon abatement from the Council's heavy vehicle fleet and waste management. This project will also assist in developing clear, workable systems to monitor emissions over time, undertake cost-benefit analysis, and make recommendations to reduce emissions.

While the Council undertook considerable carbon forest planting through its Regenesis project, there may be additional opportunities for sequestration in trees. There is also the opportunity for street tree planting to reduce the urban heat island effect, as part of the Council's Cool Street's project. This research will investigate the potential areas available for green canopy planting and the potential carbon sequestration that could be achieved.

The main deliverable of this project is a toolkit outlining some abatement opportunities of GHG emissions in the Council's heavy fleet and waste and the potential for carbon sequestration and street cooling via green planting. This kit will provide the Council with the following main outputs:

1- A fuel consumption optimization model for heavy vehicle routing. This result will particularly help the Council to reduce its emission in heavy duty vehicles, which come from the current route selection.

2- Analysis of Urban land use management to help reduce the urban heat island effect. To include analysis of GIS and satellite imagery to ascertain areas where tree planting would provide most benefit, including streets, and public and private lands.

3- A prioritized list for reducing the Council's internal, operational waste – especially to landfills. To include behavioral aspects, and if possible a trial within a specific building (e.g., Max Webber library).

4- Carbon emission and cost-benefit analysis of the project's recommended scenarios for GHG emission reduction in the three fields of heavy vehicles route optimization, tree canopy opportunities, and reducing the Council's operational waste.

The results will be presented in the form of tables, diagrams, maps, and reports where applicable.

1- Publishing of any information

Publication or presentation of material relating to this project must be in accordance with the Research Collaboration Agreement between Blacktown City Council and Western Sydney University.

2- Time table of the project

The approximate duration of the project is 18 months starting from April 3, 2017 and ending on October 3, 2018.

The narrow time frame and sequence of the research topics have been presented in the following table. Sub-projects may be re-ordered within this timeframe where agreed between the researcher and the Council.

Row	Deliverable	May 17	Jul 17	Sep 17	Nov 17	Jan 18	Mar 18	May 18	Jul 18	Sep 18
1	Literature review									
2	Initial data analysis and finding the gaps									
3	Writing a paper for comparison of the Council's measures in the electricity and gas sector									
4	Development of a fuel consumption optimization model for the heavy vehicle routing problem									
5	Analysis of urban land use management to help reduce the urban heat island effect									
6	Development of a toolkit for reducing the Council's internal, operational waste – especially to landfills.									
7	Carbon emission and cost-benefit analysis of all possible scenarios targeting GHG emissions in the three fields listed above									
8	Writing the report, and two papers on the results of the study									

3- The Project team

This project will be conducted by Western Sydney University in collaboration with Blacktown City Council, as a PhD research project. The Research Collaboration Agreement between Blacktown City Council and Western Sydney University provides mutually agreed guidelines and governance for the project. The project is being undertaken by a team of Council and University staff whose roles in the research are as follows:

Vivian Tam

Associate Professor in Construction Engineering and Management at Western Sydney University

Research Supervisor

Helen Burnie

Acting Senior Environment Officer,

Environmental Services, Blacktown City Council

John Bannister

Manager - Plant & Energy

Blacktown City Council

Donna Wallace

Senior Environmental Officer

Environmental Services, Blacktown City Council

Hoda Karimipour

Sessional Academic and PhD research scholar

Western Sydney University

Researcher

Attachment 3

Hoda Karimipour

letter of offer

Blacktown City Council
Growing with Pride

File no: F17/13

3 April 2017

Ms Hoda Karimipour
8A Orth Street
KINGSWOOD NSW 2747

Dear Hoda,

Letter of offer: Work experience research and analysis project arrangement

Hours per week: **up to 35**
Effective from: **3 April 2017**
Ending on: **3 October 2018**

I am pleased to confirm an offer of the above arrangement from Monday 3 April 2017.

The terms and conditions are that:

- The arrangement is mutually beneficial. Council receives the greenhouse gas related research and analysis outcomes we require, and achieving these outcomes also assists you in furthering your knowledge and fulfilling your PhD requirements.
- Western Sydney University provides appropriate insurance coverage for you while you conduct your research and analysis work with Council. This coverage includes but is not limited to Council sites.
- Council offers no payment for your work. Rather, you receive scholarship funds arranged through Western Sydney University.
- Council provides you with a workspace and a computer for a minimum of three days per week.
- Details of your research proposal and arrangements regarding any publications are yet to be negotiated and settled.

To confirm your acceptance of this arrangement, please sign the attached copy of this letter and forward it as soon as possible to helen.burnie@blacktown.nsw.gov.au.

I look forward to your valuable contribution to our team.

Yours faithfully,

[redacted]

Manager Environment

Council Chambers • 62 Flushcombe Road • Blacktown NSW 2148
Telephone: (02) 9839 6000 • **Facsimile:** (02) 9831-1961 • DX 8117 Blacktown
Email: council@blacktown.nsw.gov.au • **Website:** www.blacktown.nsw.gov.au
All correspondence to: The General Manager • PO Box 63 • Blacktown NSW 2148

Attachment 4

Blacktown City- Environmental Sustainability Policy

Policy Number	P000482
Subject	Environmental Sustainability Policy
Subject Area	ENVIRONMENT
Priority Area	Environment
Objective	Ensure Ecologically Sustainable Development principles and programs to enhance our existing and future environmental outcomes.
File Number	127-51-22
Inception Date	25/11/2009
Last Review Date	
Reports	PO1446 SL290144
Responsible Officer	Director Sustainable Living - DSL, General Manager - GM
Policy	**City Vision** To be a vibrant, healthy and safe City - a City of excellence. **Environmental Sustainability Policy Vision** To lead by example by embedding environmental sustainability best practice into Blacktown City Council's core business and support the community to conserve and enhance our local environment. **Policy Statement** Blacktown City Council is committed to the conservation, restoration and enhancement of our environment. In keeping with ecologically sustainable development principles, Council works to balance social, economic and environmental values and imperatives. We are working to rehabilitate our waterways, conserve and protect local bushland and wildlife, extend native habitat, improve air quality, and reduce waste and our carbon emissions to provide a healthy environment for residents of Blacktown now and in the future. We are committed to enhancing our environmental awareness and to engaging with our community to improve environmental outcomes throughout Blacktown City. We work in partnership with our community, our suppliers and other stakeholders to continuously advance our journey toward sustainability. This journey involves striving to: protect and enhance biodiversity reduce our consumption of resources take action to reduce our waste and carbon pollution engage with our community to support and encourage improved environmental outcomes. **Purpose/Objectives**

Policy Number	P000482
Subject	Environmental Sustainability Policy
	The purpose of this Policy is to provide a rationale, set of objectives and focus areas by which Council undertakes to conserve and enhance the local environment. The objectives of this Environmental Sustainability Policy are to: Identify, implement and promote best practice environmental management across Blacktown Ensure Council operates in an ecologically sustainable manner by reducing resource consumption, waste production and environmental pollution Enable, encourage and support all staff to participate in environmental conservation initiatives by providing effective training and education opportunities Encourage a holistic view of Council operations to enable us to link and balance our economic, social and environmental responsibilities Ensure compliance with relevant legislation **<u>Focus Areas</u>** This Policy will focus on the following areas: ***Our Assets*** Consider energy and water conservation in our existing buildings, the installation of energy and water reduction initiatives and staff awareness Consider environmentally sustainable options during the design and development of new buildings When considering the procurement of fixed plant for our building consider the most practical, economical and environmentally sustainable option When considering the procurement of plant and equipment consider the most practical, economical and environmentally sustainable option Our People & Settlements Council leads by example through integrating sustainability into core business and reducing its ecological footprint in its day-to-day operations Enhancement of the health and wellbeing of the Blacktown community by promoting public health best practice, encouraging physical activity, healthy eating and enforcement of legislation Reduce the consumption of resources, minimize the environmental impacts of waste, and improve recovery and diversion rates. Actively encourage the community to become involved at the local level to move towards sustainability and reduce the ecological footprint in homes, businesses, schools, and recreational pursuits

Policy Number	P000482
Subject	Environmental Sustainability Policy
	Our Water & Catchments Protect and improve the water quality of our local waterways Promote water and energy conservation initiatives to reduce consumption Pursue sustainable water management through opportunities such as stormwater harvesting, water sensitive urban design and alternative water sources ***Our Land & Biodiversity*** Support local food initiatives and strengthen existing local food networks and community gardens Protect, restore and enhance Blacktown City's biodiversity Extend biodiversity corridors through native planting ***Our Climate & Atmosphere*** Pursue opportunities to reduce atmospheric pollutants and improve air quality in the Western Sydney Basin Pursue opportunities to sequester carbon through planting locally native trees Advocate and address climate change, including reducing our greenhouse gas emissions and working towards becoming carbon neutral

Attachment 5

Blacktown City- Urban Forest Policy & Guidelines

Urban Forest Policy & Guidelines
Definition
The Urban Forest is defined as the totality of trees and shrubs on all public and private land in and around urban areas (including bushland, parkland, gardens and street trees) and is measured as a canopy cover percentage of the total area. The Urban Forest is recognized as a primary component to the urban ecosystem.

Purpose
Blacktown City has produced this document to set the policy direction and provide guidelines for the planting, and maintenance of trees.
It states our policy and provides guidelines for persons dealing with trees and shrubs found on our streets, parks, and on private property
What this document is for and how it applies
This document has been written for Council staff, members of the public, developers, and service authorities dealing with trees in the City.
This strategic document will facilitate greater collaboration with the community as well as support and inform our staff in the planting and management of trees on Council and public land. Additionally, the accompanying guidelines provide information for community members interested in understanding our methodology in the management of the Urban Forest.

Urban Forest Policy
Blacktown City recognizes that trees and shrubs are vital to the urban landscape. They provide benefits and improvements to the urban aesthetics, environment, biodiversity, climate, economy, and social wellbeing of the community.

Council will:
- Optimize the Urban Forest within the constraints of the modern urban landscape Infrastructure requirements, health and safety considerations, and development issues.
- Provide methods, designs and techniques that will minimize conflicts between trees have and the built environment.
- Involve members of the community in the selection, planting and protection of our urban forest through programs of education, promotion and consultation.
- Develop park and streetscape designs and strategies suited to our City
- Implement a priority-based program for the planting and replacement of trees.

Our policy objectives and actions

The following actions will be undertaken to achieve the Urban Forest Policy goals and objectives. These will be developed and implemented by Civil and Park Maintenance and the results of these actions will be reported to Council on a regular basis.

Objectives	Actions
Improve the health, and increase the extent, of the tree canopy cover to provide environmental and social benefits to the City	• Undertake and complete an inventory of trees based on asset management principles. This inventory will list the location, condition, and the positive and negative impacts of our existing tree population in Blacktown City. • Analyze the data collected by the tree inventory and develop a hierarchy of streets that have declining streetscape amenity and program these for replacement and infill planting. • Develop long-term strategies to increase the quantity and quality of Council's tree population in both the streets and parks. • Sequentially remove certain species of trees in streets and parks that have a high risk of failure or trees that have environmental issues and replace these with more suitable species. • Develop a replacement program that will take into account site conditions, community feedback, and tree suitability. • Stage plantings of trees within parks so that a healthy canopy of older trees is maintained, and younger replacement trees are always growing to fill gaps left by trees that are old diseased or need to be removed. • Continue to invest in the health of the urban forest by avoiding tree monocultures and planting a variety of non-invasive native and exotic species that suit their location. • Ensure that the trees within private land are protected through implementation of appropriate controls

Objectives	Actions
Improve wildlife habitat and biodiversity by providing trees and vegetation in our streets, parks and private gardens	• Carry out a survey of existing native animals and investigate which native animals and plants can be attracted and sustained in Blacktown City. • Ensure that plantings attract wildlife back into the City by maximizing shelter, feeding, and breeding opportunities. • Encourage the use of plant communities native to the City that provide native biodiversity and wildlife habitat (particularly for resident and migratory birds and other native fauna). • Work towards a long-term goal that native vegetation within our open spaces is weed free, self-sustaining and provides habitat for wildlife known to occur in the area and attract other species back into the area. • Provide and promote our reference list to guide native plantings suitable for the City, which is a summary of current knowledge within the Council and our local Bushcare community. • Develop protection measures for our local ecosystems including remaining areas of native vegetation and re-vegetation areas in accordance with our adopted Biodiversity Strategy.
Create wildlife corridors by improving the connectedness of habitat fragments across the City.	• Work to identify and achieve linkages between current habitat islands wherever possible within the parks and streetscape and other corridors provided by rail and riparian corridors
Enable the community to value, nurture and protect trees, vegetation and wildlife in their gardens, streets and public spaces.	• Produce community education material outlining the benefits of trees and providing a list of suitable species they can plant, which will not cause any long-term negative impacts to their property while still promoting biodiversity. • Expand the support given to Bushcare volunteers in their worthwhile work undertaken to provide native vegetation and wildlife habitat in our City parks and open space. • Work with the community to reduce the impact of pest species and pets on biodiversity occurring in the area.

Objectives	Actions
Provide trees that are appropriate to their location and that beautify and enhance the streetscape.	• Develop streetscape planting designs that take into account site constraints and tailor them to those conditions. • Keep up to date with new technologies and best practice to assist in resolving tree maintenance and management issues. • Develop appropriate species lists and standards for sustainable tree planting and maintenance methods for use by our staff, contractors, private developers and the community to ensure that current problems are reduced. • Look for opportunities to provide improved streetscapes across a range of issues such as pedestrian and vehicular access, cycle routes, stormwater management, and biodiversity corridors through improved management of data and networking internally.
Ensure the community is aware of and educated, about trees and vegetation, and involve them in decision making about these issues in their area.	• Providing appropriate resources, advice and education material in a number of accessible formats, such as via our website, to communicate our policies and procedures in relation to the management of our Urban Forest. • Develop a process to ensure that community views on tree and vegetation management are considered in the decision-making process.
Deliver effective and sustainable tree management programs at acceptable costs	• Carry out tree management in the City within a risk management framework. • Develop budget costing as part of the yearly management plan process by providing details of the budget required to meet the goals and objectives of the Urban Forest Policy. • Continue to collect and update urban forest inventory data regarding our current tree population and vegetation to better manage these assets.

Objectives	**Actions**
	• Ensure that tree health is maximized by providing training to staff on appropriate management techniques as detailed in the Urban Forest Strategy. • Continue to add to the significant trees and vegetation register and develop a management plan to maximize their health and longevity. • Develop performance indicators that enable us to monitor progress towards our goals and aims

Attachment 6

Blacktown City- Responding to climate change Policy

Responding to climate change

Council policy

Policy statement	
We will improve energy efficiency and transition to renewable energy to reduce greenhouse gas emissions. We aim for net-zero emissions from the electricity, fuel, and gas we use in our operations by 2030. We will work with our community to achieve the NSW aspirational targets of net-zero emissions by 2050 and become more resilient to a changing climate; especially to increases in urban heat.	
1. Scope	
2. The Policy applies to Council representatives and employees	
3. Definitions	
Council representative	Councilors, contractors, consultants, volunteers, delegates of the Council and members of Council committees who represent or act on behalf of Blacktown City Council.
Employee	Any person with an employment contract with Council and works full time, part time, or on a casual or term contract basis.
We, us, our	Blacktown City Council
Net-zero emissions	Net-zero emissions, also known as “carbon neutrality” or “climate neutrality” occurs when the level of greenhouse gases emitted into the atmosphere from human activities equals the level “removed” from the atmosphere. We become carbon neutral or reach net-zero emissions by reaching an equal balance between the greenhouse gases emitted and the greenhouse gases removed.
Resilient	Resilience enables a city’s individuals, communities, organizations, businesses and systems to survive, adapt and grow, even in the face of acute shocks such as heat waves or floods and chronic stresses such as climate change.
Climate change	A change in climate patterns apparent from the mid to late 20^{th} century onwards and attributed largely to the increased levels of greenhouse gases in the atmosphere, especially carbon dioxide produced by the use of fossil fuels.

Mitigation	In this context, mitigation actions reduce either the severity of climate change by reducing greenhouse gas emissions, or they reduce the impacts of climate change, such as increased urban heat. In some cases, the same action assists with both, for example, planting additional trees can provide cooling effects while also drawing and storing carbon dioxide from the atmosphere.

Why and how we will respond to climate vulnerability

This policy is in line with the major current international climate change strategy, the Paris Agreement, Australia's commitments under that agreement, the NSW aspirational climate change targets and the aims of the Greater Sydney Commission. Our city is especially vulnerable to increased urban heat and temperatures are expected to be more extreme in the new development areas. Increases in both heat wave temperatures and duration will negatively affect human health. Heat waves especially affect those who are older, very young and/or have chronic ill health or disabilities, and those who cannot afford means for keeping cool.

There are three policy commitment areas:

Policy commitment 1

Achieve net-zero emissions from the electricity, fuel, and gas we use in our operations by 2030.

Policy commitment 2

Adopt best practice to:

a. Mitigate the impacts of urban heat in our operations, own new assets and buildings, and when undertaking major facility upgrades
b. Minimize potable water use in our operations and implement effective stormwater management through water sensitive urban design

Policy commitment 3

c. Assist our community to reduce greenhouse gas emissions and build resilience to climate change, including through:
d. Working with the NSW Government to achieve best practice reductions in greenhouse gas emissions, potable water use, and urban heat impacts via our urban planning instruments.
e. Increasing tree canopy cover and vegetation in streets and reserves.
f. Providing appropriate public places and systems to create refuges from extreme heat for vulnerable residents.