AN INVESTIGATION INTO IMPLEMENTING NET ZERO CARBON NEW BUILDINGS: A CASE STUDY OF THE ETHEKWINI MUNICIPALITY, KWAZULU-NATAL, SOUTH AFRICA

by

NASEEMA A. ELIAS

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As the candidate's supervisor I have approved this thesis/dissertation for submission.

Signed: [redacted] Name: Dr Tirusha Thambiran Date: 3 November 2021

Abstract

Better design practices, energy efficiency, and green building materials will enable the building sector to unlock emissions savings into the future, because what is constructed today will be the future of our buildings and its associated emissions.[1]
Buildings are integral to the growth of our economy and provides a scaled opportunity to influence our environment and health positively. Buildings have relatively long lifespans and contribute significantly to energy consumption and greenhouse gas (GHG) emissions. It is vital that the development of sustainable buildings is encouraged.

The role of the building sector toward reducing GHG emissions is now better understood, resulting in various initiatives globally, to move toward being a net-zero carbon sector. While low-carbon buildings are gaining momentum in the realm of sustainable development, this study provides decision-makers with quantifiable information on the cost of reducing GHGs to aid in their prioritisation of climate actions. The eThekwini Municipality (Durban) in South Africa has a long history of developing early climate change interventions and is therefore selected as a case study.

This study analyses high emitting sectors within the eThekwini Municipality to verify global findings that the building sector is indeed the sector to offer high abatement potential at the lowest cost, and then offers an evidence-based pathway of implementation of climate actions. Specifically, as the city has committed to a zero-carbon building sector, this study presents the associated cost implications of such a commitment through the approach of determining Marginal Abatement Cost Curves (MACC) using the Climate Action Plan mitigation potential assessment for the municipality. Technical interventions to reduce GHG emissions within the MACC employed a bottom-up approach for each sector and are based on the availability and feasibility of the interventions with some engagement being conducted with Municipal stakeholders and from industry experts. The MACC presents timeframes of 2030, 2040, 2050 across key sectors and highlights that the building sector offers significant GHG reductions at the lowest cost when compared to other high emitting sectors in the eThekwini Municipality. Further to this, this study deep-dives into the most financially feasible sub-sectors within the building sector using a tool specifically developed for this study, namely, the Net-Zero Carbon Energy Efficiency Cost Model. This model explores sub-sectors within the building sector to narrow down the selection of climate change mitigation projects within the building sector. The cost model accounts for differences in lifecycle costs for buildings with enhanced energy efficiency and buildings with standard energy efficiency requirements contained within existing building regulations. It is established that shopping centres and school blocks should be prioritised within the building sector for emissions reductions. These findings should serve as a tool to assist decision-makers in prioritising climate actions that will provide a high abatement potential at the least cost.

While this study focuses on the bottom-line economics of climate mitigation interventions, it is important that a more holistic cost-benefit analysis be undertaken, to consider broader opportunity costs, risk mitigation, and savings that is associated with reducing GHGs.

Keywords: Climate Change, Net-Zero Carbon, Buildings, Emissions, Low-Carbon Economy

PREFACE

The research described in this dissertation ['thesis' for the MSc] was carried out through desktop research in the School of Agricultural, Earth and Environmental Sciences, University of Kwa-Zulu Natal, Westville Campus under the supervision of Dr Tirusha Thambiran.

These studies represent original work by the author and have not otherwise been submitted in any form for any degree or diploma to any tertiary institution. Where use has been made of the work of others it is duly acknowledged in the text.

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DECLARATION 1 - PLAGIARISM

I, …Naseema Ahmed Elias………………. declare that

1. The research reported in this thesis, except where otherwise indicated, is my original research.

2. This thesis has not been submitted for any degree or examination at any other university.

3. This thesis does not contain other persons' data, pictures, graphs or other information, unless specifically acknowledged as being sourced from other persons.

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DECLARATION 2 - PUBLICATIONS

DETAILS OF CONTRIBUTION TO PUBLICATIONS that form part and/or include research presented in this thesis (include publications in preparation, submitted, *in press* and published and give details of the contributions of each author to the experimental work and writing of each publication)

Publication in preparation: Chapter 3

Submitted to South African Journal of Science:
Elias, N and Thambiran, T. (2021) The future is a zero-carbon building sector – perspectives from Durban, South Africa.

The authors are grateful for the contributions made by the eThekwini Municipality's Climate Action Plan (CAP) project team and the Department of Environment, Forestry and Fisheries (DFFE) for their contributions and inputs toward determining a marginal abatement cost curve for emissions reductions forecasts within the Municipality.

Signed: [redacted]

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Chapter One: Introduction

This chapter provides the preliminary background, rationale, and specific context in which this research project was undertaken. This contextual summary helps set the scene for conceptualising the implementation of net-zero carbon buildings in cities and includes the aim and objectives of this research.

1.1 Background

Cities are home to 55% of the world's population and the United Nations predicts that this figure will grow to 68% in 2050, where projections for population growth are estimated to be around 9 billion people (UN, 2018). The increasing rate of global urbanisation is largely attributed to developing countries and this is evident in South Africa as already 63% of South Africans reside in cities, with this figure projected to increase 71% by 2030 (PMG, 2018).

There is a positive correlation between a country's level of urbanisation and its greenhouse gas (GHG) emissions. The increased movement of people towards cities will increase the need for development in cities and this will be accompanied by increased levels of GHG emissions in the atmosphere, to which it is estimated that there will be a global GHG increase of 226 $GtCO_2e$ by 2050 (IPCC, 2018). It is also likely that other forms of pollution will increase through urbanisation such as solid waste and air pollution. The risks from climate change are potentially long-term and irreparable, with the scientific consensus that climate change is driven by human activity. The Intergovernmental Panel on Climate Change (IPCC) established that there is unequivocal scientific evidence for warming of the climate system, with much of the key and emerging global climate risks concentrated in urban centres (IPCC, 2014; 2021). While the earth's climate has been changing for millennia, anthropogenic global warming is of significance due to unmatched rates of change. The only way to minimise the catastrophic risks associated with climate change is to accelerate the transition to a low carbon economy.

Cities will be threatened by climate change in many ways, and this includes sea-level rise for coastal cities, flooding, new disease vectors, air pollution, and an increase in the occurrences of extreme weather events such as droughts and storms (IPCC, 2018). In the eThekwini Municipality, a single storm in 2017 caused an estimated minimum of R600,000,000 in damages to municipal infrastructure, and a similar cost for a fatal storm in 2019 that further claimed the lives of 70 residents (C40 Cities, 2019a). While climate risks may be worst experienced by developing cities and nations, all cities will need to mobilise to prevent disasters. Adapting to climate change has been cemented in the 2015 Conference of Parties (COP) in Paris, or the Paris Agreement, that secured a legally binding impetus for nations around the world to reduce emissions and to support cities and local governments to ease losses and damages from climate change threats (EU, 2019). Cities are increasingly gaining recognition as key role players in implementing climate change mitigation and adaptation plans. It is especially important for developing cities to recognise their role in planning for a safe and habitable future, especially as the potential for growth and their demand for construction and development is high.

Business as usual is no longer feasible, not economically nor environmentally, and economies around the world will need to act urgently to transition towards low carbon and resilient economies. The IPCC 5th Assessment Report concludes that climate change has already resulted in unprecedented changes to the earth's atmosphere, with continued warming of the oceans and rising sea levels (IPCC, 2014). The IPCC has modelled GHG emissions scenarios that indicate a relationship with increasing temperatures and higher cumulative GHG concentrations. The results indicate that globally, should emissions into the atmosphere continue as per the current status quo (baseline emissions), this will place the earth at a 'red alert' level which means that the risks will be severe (IPCC, 2021). Figure 1 below represents a combination of two graphs from the IPCC's 5th Assessment Report that highlights the increasing risks associated with rising temperatures and higher cumulative emissions. Looking at cumulative emissions is a powerful tool in understanding the outcomes of varying emission pathways. The excerpt of the IPCC graph in Figure 1 presents the intensity of climate change risks (on the left) associated with various emissions pathways. For example, the "baseline" pathway range on the top right of Figure 1 is associated with a temperature range of 3.8° to over 4.5°C and is connected to additional risks of a high level.

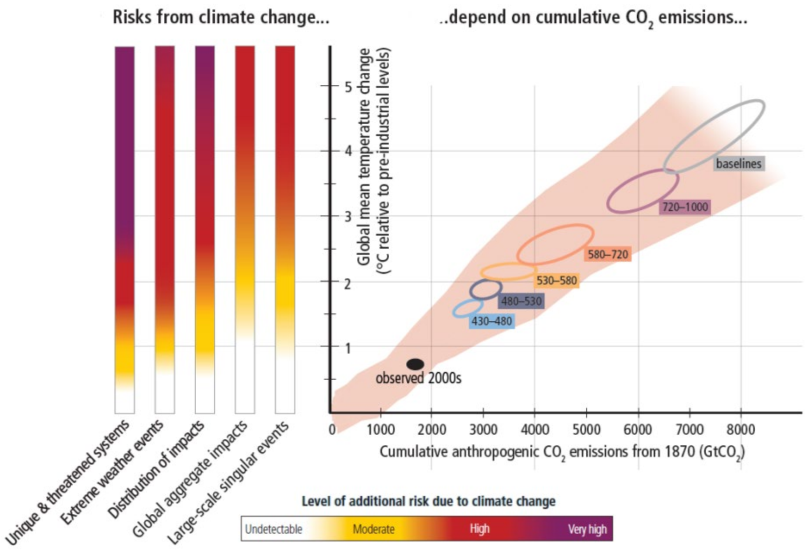

Figure 1: Risks posed by climate change in relation to rising temperatures from cumulative greenhouse gas emissions (IPCC, 2014).

The IPCC had recognised early on that globally the building sector offers the highest potential for carbon emissions reductions (IPCC, 2007) and this is further cemented by the World Business Council for Sustainable Development (WBCSD) that showed global energy use within buildings offered emission reductions up to 60% by 2050 with the use of existing efficiency and renewable technologies (WBCSD, 2009). Buildings are where citizens spend most of their time – from the workplace to their residences, learning institutions, and places of worship. The built environment, specifically the building sector has an important role to play in addressing the impending impacts of climate change. The building sector has a significant environmental impact in terms of its usage of natural resources, production of waste, and its contribution to GHG emissions into the atmosphere.

Post the historically significant Paris Agreement in 2015, countries around the world committed to targets and disclosure of their climate change mitigation policies and programmes, yet the role those local authorities could play remained unclear with cities remaining as 'non-state actors' at the Conference of Parties. It is important to note that cities are uniquely posed to mitigate climate risks with the ability to mobilise resources and play an effective role in planning and influencing climate action. Specifically, local governments may be better poised to acknowledge and recognise innovations from residents and utilise progressive research from its residents and institutions more quickly than National governments. To address this planning need, organisations such as C40 Cities Climate Leadership Group (C40) and ICLEI (Local Governments for Sustainability, that was initially established as the International Council for Local Environmental Initiatives) developed programmes that cities could collaborate with, and published sets of research that translate the 'required by science' targets within the United Nations Framework Convention on Climate Change (UNFCCC) processes into workable thematic areas for cities (C40 Cities, 2017; ICLEI, 2018). Included in the C40 Cities' publication 'Deadline 2020' is low carbon pathways for cities that are modelled based on their economic and emissions contexts (C40 & ARUP, 2016). The publication 'Deadline 2020' further unpacks the targets into practical focus areas that include a) Energy and Buildings, b) Transportation and Urban Planning, c) Food, water, and waste, d) Adaptation implementation and, e) Air quality (C40 & ARUP, 2016).

This study utilises a sectoral perspective that is based on emissions from its end-use allocations, which is useful to highlight where efficiencies can be achieved. Interestingly, the perspective of GHG emissions arising from the building sector is a growing area of study and implementation from various organisations and cities around the world. A report produced by C40 and McKinsey includes 7 out of 12 priority actions that relate to energy and buildings (C40 & McKinsey, 2017). Within the portfolio of ICLEI, there is an aligned focus on buildings through the Building Efficiency Accelerator programme that is part of ICLEI's Low Emissions Pathway that includes objectives for carbon-neutral infrastructure (ICLEI, 2018). Through such initiatives, GHG emissions arising from the building sector have emerged as a growing area of study and implementation from various organisations and cities around the world (WGBC, 2021).

From a sectoral perspective it has been found (WCGC, 2021; IPPC, 2014) that transport and building activities contribute at least 70% to the global share of GHGs from cities. The building sector accounts for approximate a third of global energy use, and is therefore one of the largest contributors of GHG emissions (ICEI, 2018). The Global Alliance for Buildings and Construction, a programme of the United Nations, further estimates that the building sector contributes 28% of global GHG emissions, with a further 11% of emissions arising from the accounting and consideration of embodied[1] emissions from building materials and construction activities (GlobalABC, 2018).

In addition to carbon emissions, the building sector adds other GHGs into the atmosphere such as halocarbons, chlorofluorocarbon, hydrochlorofluorocarbons, and hydrofluorocarbons which are found in some electrical appliances used throughout the operations of some building types (Global ABC, 2018). Given that buildings generally have a life span that can range from 40 to over 100 years (C40 Cities, 2017) reducing the output of carbon emissions of buildings from the onset, can offer emissions savings throughout its lifespan. While there are differing statistics, albeit slightly, on the GHG emissions from the buildings sector due to differing approaches detailed in the respective organisations' methodologies, these are promising analyses for the building sector even though being assessed at a national level where methodologies for GHG accounting is different to that of a local authority. For context into the economies of local authorities, it is vital for similar sets of analyses at a local level.

To this extent, as part of its programme that provides direct support to cities, C40's Building Energy Programme 2020 includes a component that provides resources and expertise to

[1] Embodied carbon emissions refer to GHGs that are inherent to the material i.e. GHG emissions that occur during the manufacture and transportation of building materials

implement new buildings that are of a net-zero carbon profile within four South African cities (eThekwini Municipality, City of Cape Town, City of Johannesburg, and the City of Tshwane), all of whom have pledged ambitions of achieving net-zero carbon buildings (both new and existing buildings by 2030 and 2050 respectively) (C40 Cities, 2018a). The buildings and energy programme was born due to the high rates of development within developing cities and the need to reduce GHG emissions from the building sector.

In the eThekwini Municipality for example, the construction of new buildings with a net-zero carbon profile has become a core focus of the City's climate change mitigation agenda and is largely supported by C40 Cities (EThekwini, 2021). Net-zero carbon buildings refer to buildings that are highly energy-efficient and that are completely powered from renewable energy sources either on-site and/or off-site and may include a portion of GHG emissions off-sets that would match the building operation's energy consumption (GBCSA, 2019). Establishing all new buildings as 'net-zero carbon' involves raising the standards for new buildings in the eThekwini Municipality - going beyond the national requirements for energy efficiency in buildings.

The eThekwini Municipality has a strong focus on climate change management and prioritises climate change mitigation and adaptation in the Durban Climate Change Strategy (EThekwini, 2016). This is significant for South Africa as the eThekwini Municipality contributes 5% of the country's total GHG emissions, responsible for 29,025,638tCO_2e, and is the country's third most populous city that includes the port city of Durban and surrounding areas (ETH, 2017).

From the publication "Building Energy Efficiency" from the World Resources Institute in 2016, the global building sector can provide substantial GHG emissions reductions at the least costs relative to other sectors and that it is a sector that should be addressed by decision-makers and role-players (WRI, 2016). The building sector was long documented as a key role-player in climate change mitigation from the IPCC's 2007 Assessment Report where sectoral contributions to GHG emissions were analysed, with the building sector displaying a substantial potential for climate change mitigation into the future. More recently, South Africa has published a set of mitigation potential analyses that look at the GHG emissions reduction potential of each sector and considers the associated net costs and social benefits, thatresulted in the buildings and transport sectors dominating the top 25th percentile, meaning that if 25% of the country's available lifetime mitigation potential is applied then these are the sectors that should be prioritised due to relatively low costs and ease of implementation (DEA, 2016). These are promising analyses for the building sector even though being assessed at a national level where methodologies for GHG accounting are different from that of a local authority. For context into the economies of local authorities, it is vital that a similar set of analyses be done at a local level. Various cities across the world have conducted these analyses and often include a marginal abatement cost curve (MACC) being produced across the cities' economic sectors (DEA, 2016).

These studies have contributed to a growing recognition that the global building sector offers a substantial potential for carbon emissions reductions with over 3000 cities making public commitments to addressing climate change from the perspective of the building sector (C40 Cities, 2017). C40 Cities participating cities devised their commitments from the science behind the Paris Agreement and allows cities within the C40 Cities network to achieve their reductions within their allocated carbon budgets. It is vital that the targets set by role-players are ambitious or at least aligned with the targets of the Paris Agreement, and it is noteworthy that the building sector is receiving global attention in terms of addressing climate change. C40

Cities within South Africa namely, the eThekwini Municipality, the City of Cape Town, the City of Johannesburg, and the City of Tshwane have also made public declarations through the C40 platform, alongside several developed country cities (e.g., London, Montreal, and New York City), committing to the following:

1. To have implemented that all new buildings will have a low to zero carbon profile by 2030
2. That all existing buildings will have a low to zero carbon profile by 2050
3. That all city-owned buildings will have a low to zero carbon profile by 2030.

A city's ability to effectively manage future climate and developmental needs rest with decision-makers, who often seek solutions that can deliver maximum benefits at the least cost scenario. To equip decision-makers with all the information for proper climate change management, it is important to understand the mitigation potential of sectors that is accompanied by a holistic understanding of any costs and cost benefits that may arise. There is currently little to no data on the feasibility of long-term GHG reducing activities within sectors in the eThekwini Municipality, and especially for the building sector, which is a key focus for climate change mitigation in the eThekwini Municipality. Through C40's involvement in the eThekwini Municipality, a range of mitigation potentials have been determined yet there lacks an understanding of the feasibility of these activities.

Feasibility assessments encompass a range of economic, technical, and legal factors that is largely project specific. For purposes of this study, the aspect of costs per abatement activity is assessed and is limited to its net costs. On a national level, there exists information for the costs of sectoral mitigation potentials and includes quantification of jobs that will be created and of social benefits that could arise from mitigating activities. Broader opportunity costs, risk mitigation, and savings that is associated with reducing GHGs too broad to be incorporated in this study that focuses on the bottom-line economics of climate mitigation interventions, however it should be an important aspect for future studies.

1.2 Defining the scope of this study

The built environment, specifically the building sector has a massive role to play in addressing the impending impacts of climate change (GBCSA, 2019). The building sector has a significant environmental impact in terms of its usage of natural resources, production of waste, and its contribution to GHG emissions into the atmosphere – which is the primary focus of this study. It has been established earlier in this chapter that the building sector can provide substantial GHG emissions reductions and that it is a sector that should be addressed by decision-makers and role-players.

There is a perception in the building industry that green buildings have a cost premium (the green premium) in comparison to standard specification buildings, and this perception remains true for net-zero carbon buildings (GBCSA, 2019). The cost differences for net-zero carbon buildings have not been adequately researched to date and there are a few local and more international studies that contribute towards providing the business case for net-zero carbon buildings. While a discerning voice of reason may conclude that this perception may very well be higher than the reality, there is a need to investigate whether the building sector is indeed the sector that will provide the most carbon emissions reductions at the lowest cost in the context of a developing city. Since this dissertation focuses on implementing net-zero carbon buildings as part of a city-wide regulatory environment, it is important to understand the sectoral cost implications and the costs of interventions in the building sector, to denote the feasibility of such a regulation.

This research thus explores existing literature on the topic of net-zero emissions to understand the role of the building sector on climate change and to further unpack the definition of a net-zero carbon building. To aid in the advancement of climate change mitigation efforts in cities in South Africa, it is particularly important to unpack the feasibility from a cost perspective of achieving a net-zero carbon building. A case study of the eThekwini Municipality is thus used to investigate aspects of feasibility with a primary focus on costs through quantitative analyses of sectoral data obtained from the eThekwini Municipality and the C40 Programmes within the Municipality to develop a MACC. The building sector is further scrutinised in a cost model, developed for this study, which determines the lowest cost sub-sectors within the building sector, to support prioritisation of interventions within the building sector. The scope of the analyses will be limited to emissions within the jurisdiction of the Municipality and the costs will only include the capital and operational costs associated with the activity and will include and cost savings and/or revenue achieved.

The outcomes of this study are expected to contribute to the knowledge base and information in the city and present recommendations to inform actions of decision-makers and investors.

1.3 Aims and objectives

The aim of this dissertation is to present a review of current research on buildings within the context of net-zero and to investigate the cost of GHG abatement interventions within the building sector in the eThekwini Municipality.

To meet the above aim, the following objectives were determined:

1. To evaluate the costs in achieving the abatement potential for each high-emitting sector in the eThekwini Municipality
2. To determine the sector that can offer the highest abatement potential at the least cost in the eThekwini Municipality
3. To develop and implement a tool to investigate the costs associated with implementing specific interventions within the sector that is determined to offer the highest abatement potential at the least costs
4. To offer a suite of recommendations that would inform the pathway for implementation of climate actions in the eThekwini Municipality.

1.4 The research questions

Net-zero carbon buildings provide an opportunity for cities to reduce GHG emissions and assist their nations to meet their international targets, as required by science, while also playing a role in supporting and securing the security of electricity to end-users. Addressing climate change concerns whilst still optimising business controls has conventionally been conflicting goals. Examining the cost curves of GHG reducing activities within sectors of the eThekwini Municipality will assist decision-makers and policy-makers to address climate change in a way that does not prohibit business growth nor the service delivery of a city. This study aims to evaluate the financial feasibility of net-zero carbon buildings to assist decision-makers in how to roll out such projects.

There are currently various international movements towards regulating new construction to be of a net-zero carbon emissions profile, and in South Africa, four cities are moving ahead with the implementation of this, namely, the eThekwini Municipality, the City of Cape Town, the City of Johannesburg, and the City of Tshwane. Furthermore, these cities have also made a public declaration to realise a net-zero carbon status for all buildings by 2050 (C40 Cities, 2017).

This study will focus specifically on the eThekwini Municipality, to enhance the understanding of the practicality of implementing such a programme, specific to the local economic and environmental conditions. Nonetheless, there are aspects of this assessment that could potentially be applied to other cities in a similar developing country context.

The main questions that this study would investigate include the following:

a) What is the cost associated with reducing GHGs from the building sector and other high emitting sectors within the eThekwini Municipality?
b) Is the building sector the sector that can offer the most amount of GHG reductions in line with transitioning to a zero-carbon economy at the lowest input cost in the eThekwini Municipality?
c) What are the drivers of energy consumption in buildings?

d) What are the costs of implementing net-zero carbon building principles compared to retrospectively applying the same for existing buildings, for various building typologies?
e) What recommendations can be made for the successful implementation of a feasible emissions reduction project?

1.5 Significance of the study

This dissertation provides a review of current research on buildings and their role in climate change mitigation and addresses a gap in data by developing a cost curve for GHG abatement potentials for significant sectors within the eThekwini Municipality. Feasibility gaps will be addressed through reviewing existing literature on GHG mitigation activities within sectors and through developing a MACC in a city-specific context of the eThekwini Municipality in South Africa. It is important to note that there is substantial evidence that shows a relationship between GHG reductions with improved health through improving air quality and quality of living in various aspects, and due to the broad nature of unpacking these benefits, these externalities will not be quantified in this study that is focused on costs.

The research will provide decision-makers with an overview of the bottom-line cost implications of reducing GHG emissions across various sectors in the eThekwini Municipality for time-frames going up to 2050. Thereafter, a tool developed for this study, the Net Zero Carbon Energy Efficiency Cost Model, will further explore sub-sectors within the building sector to further narrow down the selection of climate change mitigation projects within the building sector.

The study will attempt to answer the research questions in a twofold manner: firstly, the concepts of net-zero carbon and the influences from the building sector to climate change will be unpacked and described. Second is the determination of cost curves for sectors within the eThekwini Municipality through an analysis of existing literature to obtain the mitigation potential of sectors and collating data on localised activity costs projecting these costs into time frames of 2030, 2040, and 2050. This study will further explore the impact of the building sector, specifically net zero carbon buildings, on GHG levels in the eThekwini Municipality.

This comparative analysis of the potential for reducing GHGs within sectors and their associated costs until 2050 will outline the basis for recommendations to be made in the implementation of any policies or regulatory framework regarding emissions reductions and energy efficiency in new buildings.

1.6 Expected outcomes and impacts

The study will contribute uniquely towards knowledge base in the following manner:

- The research will provide decision-makers with a current and simplified overview of the cost implications of reducing GHG emissions across various sectors, specific to the eThekwini Municipality.

- The research will seek to scrutinise the mitigation potential and costs of specific interventions that would reach net zero carbon buildings in both new and existing buildings for both the residential and commercial sectors within the eThekwini Municipality.

1.7 Limitations of the study

An investigation into the costs alone will not provide finality for any policies or decisions and will serve as only a part of the tools required for decision-making. There is a need for an investigation into the various factors that play a part in deciding on whether the enforcement of low to zero carbon buildings is feasible, and these factors include life cycle costs, implementation, compliance, and enforcement, as well as external environmental, economic, and social impacts. Appropriate and evidence-based research must be conducted to bridge the divide between perceptions of stakeholders and the realities of a net-zero carbon building sector, which will in turn influence the uptake of the market. It is also important to note that the optimisation of a business case can be achieved through alignment with positive environmental impacts and market trends to promote a shared value business case where profits are maximised while also maximising benefits to communities and the shared environment.

1.8 Structure of the Thesis

This thesis is presented in five chapters, where Chapter One outlines the introduction, and the final chapter frames the recommendations and closing remarks. In Chapter Two, a literature review that studied relevant local and international literature pertaining to the current and future role that the built environment plays in addressing the climate change problem, where it is important to define the term ‘net-zero carbon’. The review also looks at the drivers of rising GHG emissions within the building sector and contextualises the state of the building sector in relation to climate change mitigation in the eThekwini Municipality. Following this review, the outcome will comparatively analyse the factors that impact the feasibility of such a regulation with a specific focus on the cost of the sector as this is important considerations for policy-makers within a developing country context. It became apparent during the author’s research that there was no current evidence base to corroborate that the building sector is the sector with the lowest cost pathway to achieving high abatement levels of GHG emissions within the eThekwini Municipality, and this chapter unpacks this research gap.

A MACC was developed to explore the feasibility of enforcing a net-zero carbon building sector, and Chapter 3 describes the approach to developing the MACC and provides an analyses of the results. This chapter will provide scientific analyses of the considerations towards the feasibility of sectors within the eThekwini Municipality that can be read by all stakeholders to deduce conclusions for their context.

Chapter 4 presents a review of local and international literature and regulatory environments before portraying localised cost-benefit analyses for the implementation of specific actions within the sector that has been established to offer the lowest cost interventions to addressing climate change from a city perspective. The 'Net-Zero Carbon Buildings Energy Efficiency Cost Comparison' tool was developed specifically for this study, to highlight the lowest cost pathway of actions within the eThekwini Municipality's building sector. It should be noted that Chapters 3 and 4 have been written in form of research papers, with Chapter 3 currently under review by the South African Journal of Science. As such there may be an overlap in background and references.

Chapter 5 summarise the information researched and reviewed to make meaningful conclusions and recommendations on a feasible way forward in lieu of cities looking into the pathways to achieving significant GHG emissions reductions. An overview of net-zero carbon new buildings will be provided, with the results of the research and main observations being further discussed and unpacked. This information can be used by all stakeholders for planning purposes, and to better the understanding of the value proposition of the new buildings sector in the transition to a low carbon economy, within a developing city context.

There are also recommendations to be made for future research relating to the implementation of net-zero carbon buildings, specifically the augmentation of this research to expand and refine the research. Conclusions are then provided, summarising the outcome of the research, and emphasizing the importance of the research in the space of local governments in realising climate action.

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Chapter 2: A critical analysis of the concept of Net Zero Carbon Buildings

The purpose of this literature review is to gain an understanding of relevant existing research on net zero carbon buildings and their implementation for the purposes of reducing GHG emissions. This review is conducted within the broader context of climate change in cities and further unpacked within the context of the case study area of the eThekwini Municipality. This review presents various factors that contribute towards the drivers of energy use in buildings and how the building sector influences climate change. The literature review presented in this chapter provides a context to net zero carbon buildings while highlighting current ideas that have been published in this space, with a critical analysis of the relative strengths and weaknesses thereof. A review of pertinent approaches and methods to estimating emissions and costs related to net zero buildings is also included.

2.1 Role of the Urban Building Sector in Climate Change Mitigation

2.1.1 Cities and climate change

By definition, cities are non-agricultural and are developed with a concreteness of anthropogenic infrastructure that includes but is not limited to residential houses, commercial buildings, roads, and railways (OECD, 2020). Collectively, cities around the world contribute about 70% of global GHGs (C40 Cities, 2017). As hubs of businesses, trade, and innovation, cities hold many opportunities and influence to assist in reducing the worst effects of climate change and further have the potential to unlock the best solutions to global climate change challenges (C40 Cities & McKinsey, 2017). Local authorities and policy-makers should improve upon developmental strategies to accommodate for increasing population and urbanisation, and to ensure that sufficient investments are made into the urban infrastructure so that the sustainable development goals are met. Cities are being seen as an integral role-player in addressing climate change as any policies and strategies would necessitate a tailored approach that is based on the city's context, such as future climatic risks, economic activities, and service delivery challenges.

The accounting of GHGs in cities is becoming increasingly widespread (Albert, 2019). The calculation of GHGs depends on various factors such as the methodology used, the emission source, conversion factors used to calculate, the geographic location, and the local city context (GPC, 2014). The GHG Protocol for cities currently allows for two reporting approaches for GHG emissions from cities, where the first approach categorises emissions into "scopes" that indicate the location of the emissions source in relation to the reporting city, and the other looks at emissions per sector activities (GPC, 2014). In a study by C40 Cities (C40), it is presented that cities may contribute far more to GHG levels when consumption-based emissions are accounted for (C40 Cities, 2018b). Consumption-based emissions refer to the life-cycle emissions of products and/ or services that are consumed or used within a geographical area, but that may not have originated or been produced within the region's boundaries where the demand lies (C40 Cities, 2018b). This encourages focus on the responsibility of consumers (C40 Cities, 2018b). This concept is of particular importance as it gives a greater impetus for the role of cities in the fight against climate change. When looking at consumption-based emissions, emissions can largely be concentrated in just a few cities in a country as in the case of Seoul - where its residents are responsible for almost 50% of South Korea's total GHG emissions, or when looking at the consumption-based emissions of London, Manchester, and Birmingham that account for more than 20 percent of the United Kingdom's emissions, and where New York City, Chicago, and Los Angeles contribute around 10 percent of the emissions of the United States of America (C40 Cities, 2018b).

GHG emission reduction targets, regardless of whether appropriate to the science, have been committed to by most nations around the world through the Paris Agreement, despite the Paris Agreement setting down a temperature increase limit of 2 degrees Celsius, with the ambition of 1.5 degrees Celsius from before pre-industrial levels (Le Quéré *et al*, 2016). However, it may be argued that these temperatures increase limits did not come with prescriptive pathways, where nations and stakeholders had to develop and set their own pathways to GHG emissions reductions (Pauw *et al*, 2019). The IPCC published a set of emission scenarios that will determine the future greenhouse gas concentrations and the associated temperature increases. Illustratively, the Representative Concentration Pathways (RCPs) describes a set of four projections that are based on anthropogenic greenhouse gas emissions that are primarily driven by global population sizes, economic activities, energy usage, land-use patterns, and climate policy (IPCC, 2014). Setting prescriptive pathways for nations at past COPs has generally been intertwined with an array of political factors involved in climate change that include economic, social, and historical factors (Le Quéré *et al*, 2016). There is a range of concerns raised by countries when disaggregating the carbon budget such as the responsibility for historical emissions, requirements for economic growth, and per capita emissions. The Paris Agreement has since provided with political consensus on the understanding that the world needs to limit the temperature increase to 2 degrees Celsius from preindustrial levels in place, leaving the technical details on implementation to be key to mitigating the worst impacts on climate change (Le Quéré *et al*, 2016).

There is currently no agreed-upon method to divide the budget (Le Quéré *et al*, 2016). The implications of the Paris Agreement for cities were largely unclear until organisation such as ICLEI and C40 produced studies to assist. A set of research entitled “Deadline 2020” produced by C40 and ARUP (2016) outlined city based GHG emissions reduction pathways to support its member cities. C40 calculated an overall ‘carbon budget’ for its network of cities, and based on several factors, categorised cities in a “peaking” or “declining” trajectory. The factors included the cities GHG emissions per capita and in addition the relationship between city GDP and GHG emissions (C40 & ARUP, 2016). The “declining” trajectories refer to C40 cities that have a GDP per capita over USD15,000 while the “peaking” pathways refer to C40 cities with a GDP per capita that is under USD15,000 and essentially allows for developing countries to emit GHG emissions for a longer period, with GHG emissions climaxing at a later stage than developed countries (C40 & ARUP, 2016). This is to allow for economic growth in developing countries as economic growth is largely linked to the output of carbon emissions. However, the later a city is allowed to peak its GHG emissions, the more difficult it will be to reduce GHG emissions to reach the 2050 targets. As all cities (and nations) have similar targets to reach the desired temperature limit increases, the more GHGs a city emits will result in a steeper decline later. It is important to note that C40 Cities models their 2050 targets as zero-carbon emissions, with future years seeing negative emissions (C40 & ARUP, 2016). This is aligned to the terms of the Paris Agreement that the carbon budget must be shared in ways that require a convergence of emissions by 2050 to remain within the pathway with the highest likelihood of safety (Le Quéré *et al*, 2016).

The research categorised four city typologies that would assist a city in planning its future GHG emissions scenarios and they are as follows:

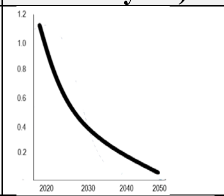
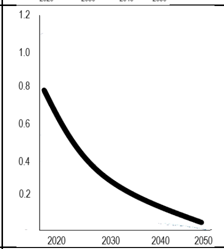
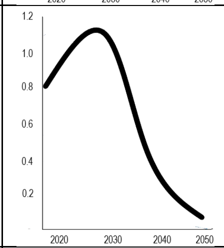
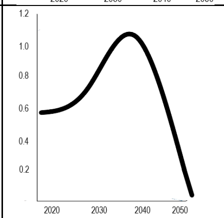
- “Steep Decline” – refers to C40 cities that urgently require to immediately curb emissions and are adequately developed to implement these actions. Examples include the City of Toronto, New York City, and the City of Melbourne.

“Steady Decline” – refers to C40 cities that are adequately developed but require a less rapid rate of emissions reduction than the “Steep Decline.” Examples include Stockholm, London.

“Early Peak” – refers to C40 cities that have higher than average emissions per capita and while urgent action is required to curb emissions, the city’s development and economic status limit this. Examples include eThekwini Municipality and the City of Cape Town.

- “Late Peak” – refers to C40 cities that allow for a late emissions peak, based on the cities’ development and lower emissions per capita status. Examples include the city of Amman in Jordan and the City of Quito from Ecuador (C40 and ARUP, 2016).

Table 1: Summary of city typologies described within C40's Deadline 2020 publication (C40 & ARUP, 2017).

City Characteristics	Mitigation pathway	Description	Pathway Graph (Annual Emissions $GtCO_2e$/year)	Example Cities
High GHG per Capita; and High GDP per Capita.	Steep Decline	Immediately implement actions to curb emissions		New York City Toronto
Low GHG per Capita; and High GDP per Capita.	Steady Decline	Less rapid rate of emissions reduction than the “Steep Decline.”		London Seoul
High GHG per Capita; and Low GDP per Capita.	Early Peak	Urgent action required to curb emissions limited by the city’s development and economic status.		Durban Cape Town
Low GHG per Capita; and Low GDP per Capita.	Late Peak	Allows for a late emissions peak, based on the cities’ development and lower emissions per capita status		Amman Caracas

While collectively responsible for the majority of emissions, cities and in turn its residents face the most severe risks from climate change (Pauw *et al*, 2019). Recent research has shown that cities will experience the most life-threatening risks from climate change that include sea-level rise, heat severity, terrestrial and coastal flooding, new disease vectors, air pollution, and water scarcity (IPCC, 2018). Around 90% of all urban areas are coastal and provide residency to most of the world’s populations (C40 Cities, 2018a). Risks from climate change include extreme weather events such as storms that could significantly damage urban infrastructure and private assets. Significant damage to access points into cities may also cut off supplies or rescue teams into cities (World Bank, 2018). The World Meteorological Organisation statement on the State of the Global Climate (2019) indicated that in 2018 alone, extreme weather events affected 62 million citizens and displaced at least 2 million people (WMO, 2019). Climate change impacts can be devastating to lives and livelihoods and the most vulnerable of communities will be affected, as cities like Sierra Leone in Africa face threats of deadly landslides and where millions of residents have been displaced by devastating floods in South Asia (Hallegate *et al*, 2017). Even so, the economic impacts of intensification of extreme weather events linked to anthropogenic climate change have no boundaries, where the United States of America (USA) experienced losses and damages that incurred an estimated cost of $155 billion from two hurricanes events in 2017 (WMO, 2019). Overall, it has been long assessed that the costs of extreme weather events alone could reach 1% of world GDP each year if no action is taken according to the Stern Review (Stern, 2007).

The Paris Agreement provided the impetus for adaptation to be given an equal footing to mitigation, and to provide technical and financial support to developing nations that may require such (Pauw *et al*, 2019). Mitigation measures to combat and limit the temperature increase largely involve reducing carbon emissions that are derived from the burning of fossil fuels for energy needs. With the understanding that reducing carbon emissions is no longer enough to halt the adverse effects of climate change, climate change adaptation refers to efforts that aim to reduce vulnerability and to strengthen the resilience of natural and built environments, and to communities (Hallegate *et al*, 2017). It is important to note that one of the biggest economies in the world infamously withdrew from the Paris Agreement in 2017. Despite this cities, businesses, and organisation wherein representing USD9.45 trillion within the USA mobilised and created a movement to compensate for the lack of political leadership and publicly declared their commitment to upholding the terms of the Paris Agreement (Wearestillin, 2019). Since the public announcement by the government of the USA, cities have accelerated their drive towards taking climate action and have signed several public commitments on various platforms such as “wearestillin.com” (Wearestillin, 2019).

Cities will thus need to relook at the way they develop their built environment and transport systems so that it is built to lock in carbon emission savings and achieve the emissions reductions that are required by science. City (local) governments can serve as best practices and case study examples for climate action and in turn may reap the benefits of improved service deliveries that have lower operating costs. As hubs of business, modernisation, and innovation, cities have the potential to unlock the best solutions to global climate change challenges (C40 Cities, 2019a).

2.1.2 Buildings and climate change

It is projected that by 2050 the global population will increase to over 9 billion people, with around 70% of this population living in urban environments (UN-DESA, 2019). This means that there will be a significant demand for new buildings by 2050. Global projections for 2050 show that the floor area in buildings will increase by 100%, equating to over 415 billion m² which will escalate the amount of GHGs into the atmosphere (WBCSD, 2018). These projections indicate that population growth will increase by over 20% whereas the floor area will double. The building sector contributes to about a third of global energy use and existing research provides a range of 25 – 38% estimated for its global GHG emissions contribution (Global ABC, 2018). C40 published that the buildings sector accounts for a third of global GHGs and refers to only the operational emissions of the building, while ICLEI attributes a quarter of global GHG emissions to the buildings sector and refers to more emissions arising from beyond just the building services (C40 Cities, 2017; ICLEI, 2018). The discrepancy in the contribution of the building sector to GHGs from C40and ICLEI, the leading organisations that work with cities, is the result of differing translations of GHG contributions. ICLEI includes embodied or embedded emissions from the buildings sector which refer to emissions that are inherent to the material i.e., GHG emissions that occur during the manufacture and transportation of building materials (ICLEI, 2018). C40 reports on emissions from the operational activities of buildings that are independent of emissions arising from the construction and embodied emissions from building materials and furnishing, which could add a further 11% of global GHG emissions (Global ABC, 2018). Both perspectives however signal that the building sector is a major contributor to GHGs and it is noteworthy to see organisations that are engaged with the sector for climate change mitigation opportunities. While the building sector is a major contributor to GHGs, the sector provides significant abatement potential as it is further projected that the building sector could offer emission reductions of up to 60% by 2050 when utilising energy efficient and renewable energy technologies (WBCSD, 2018).

However, it is important to note that the building sector only becomes a leading contributor to GHGs from the perspective of an end-user. In South Africa, the energy sector directly accounts for over 80% of emissions (EIA, 2015). It could be argued that reviewing the sources of energy would better manage emissions. However, the costs associated with decarbonising South Africa's energy sector can amount to ZAR3 trillion and will further necessitate substantial upgrades and reworkings of the current energy infrastructure (NBI, 2021). The IPCC has long recommended the inclusion of energy efficiency enhancements in existing sectors when investing in power plants to ensure broad energy security, as well as reduced costs and emissions (IPCC, 2007). It is important that all sectors, stakeholders, and parties unit in their efforts to reduce GHG emissions, to lessen the burden on single actors and so that the world can collectively act and recover (Pauw *et al*, 2019). Reductions in emissions through energy efficiency measures from sectors across the board can reduce the cost of transforming the power sector.

Research points to the building sector being able to reduce significant amounts of emissions. This high abatement potential of the building sector is further corroborated in C40's international research project, Deadline 2020 that was completed in collaboration with consultancy firm ARUP (C40 & ARUP, 2016). However, similar research and work are done by ICLEI and IEA (ICLEI, 2018; IEA, 2020). Despite this, the IEA still shows an increase in energy use within buildings in 2019 (IEA, 2020). This suggests that it is more important than ever for policy-makers to stimulate the market for efficiency within buildings. Deadline 2020 serves as a guideline to C40 member cities on how to calculate their pathway to emissions reductions based on the remaining carbon budget and their economic performance. This research and guidelines outline a series of actions that cities can prioritise based on sectors that offer high abatement potential (C40 & ARUP, 2016). High abatement sectors are prioritised to achieve the greatest amount of GHG emissions reductions and are Urban Planning, Transportation, Energy, Buildings, and Waste (C40 Cities & McKinsey, 2017). While the energy sector looks more at deploying clean energy sources to buildings, the building sector focuses on reducing GHG emissions from the use of electricity within buildings. C40's research on these key sectors looked at the GHG mitigation actions and interventions for each of these sectors and modelled pathways that represent the implementation of activities within time frames. The building sector is described as the only sector that contains the most number of actions (71%) that should be set up before 2020 (C40 & ARUP, 2016). These are promising analyses for the building sector even though being assessed at a national level where methodologies for GHG accounting is different to that of a local authority. For context into the economies of local authorities, it is vital for similar sets of analyses at a local level.

The built environment is a critical part of the climate change problem in cities and urban buildings can act as a scaled response to mitigating anthropogenic climate change (Architecture2030, 2021). Buildings also have a longer life span range than that of coal-fired power stations that have an average operating life of around 40 years (IEA, 2017). Building stocks typically have lifespans from about 40 to over 100 years. Action to ensure that buildings are designed for the future of the city and importantly with low to zero carbon profiles that will remain throughout its lifespan will thus contribute to a healthy, safe, and resilient city. The IPCC encourages consideration of energy efficiency enhancements when investing in increasing energy supply to ensure energy security, as energy efficiency is more cost-effective while abating GHG emissions and air pollution (IPCC, 2006). Energy efficiency is thus recognised as a key component in climate change mitigation measures.

In addition to reducing GHG emissions, buildings can also act as a scaled solution to improving urban resilience in the face of growing populations and impending pressures from climate change such as extreme weather events (EThekwini, 2021). Weather, climate, and water disasters that occurred between 1970 and 2019 resulted in economic losses of over USD3.6 trillion and over 2 million lost lives (WMO, 2021). Erecting structures and buildings that are resilient to future climate pressures will provide cities with a healthier and safer environment for urban dwellers.

The recognition that the global building sector offers a substantial potential for carbon emissions reductions is supported by cities around the world. Over 3000 cities have made public commitments to addressing climate change from the perspective of a building (Global ABC, 2018). C40 participating cities devised their commitments from the science behind the Paris Agreement and this allows cities within the C40 network to achieve their reductions within their allocated carbon budgets (C40 Cities, 2019a). It is vital that the targets set by role-players are ambitious or at least aligned with the targets of the Paris Agreement, and it is noteworthy that the building sector is receiving global attention in terms of addressing climate change. C40 Cities within South Africa namely, the eThekwini Municipality, the City of Cape Town, the City of Johannesburg, and the City of Tshwane have also made public declarations through the C40 platform, joining the ranks of cities such as Copenhagen, London, Los Angeles, Montreal, New York City, Paris, Portland, San Jose, and many others committing to the following (C40 Cities, 2019a):

1. To have implemented that all new buildings will have a low to zero carbon profile by 2030
2. That all existing buildings will have a low to zero carbon profile by 2050
3. That all city owned buildings will have a low to zero carbon profile by 2030.

2.1.3 Defining a net-zero carbon building
To achieve a state of zero emissions, all emissions introduced to the atmosphere through human activity, such as the burning of fossil fuels from vehicles, must be reduced as much as possible, and the remainder to be removed (WRI, 2019). The concept of zero-emissions can then apply to a specific project, area, or building and is always within a defined period (WGBC, 2021). It is also important to contextualise how the term *net-zero carbon* fits in with other popular references that include, but not limited to; carbon neutrality, climate-neutral, carbon-free, zero emissions. These terms are used interchangeably and conceptualise a similar conclusion – achieving net-zero carbon emissions by not producing carbon altogether, or through the

balancing of quantified carbon emissions with carbon removal through carbon offsetting over a defined period.

The principle of net zero carbon being applied to the building sector is thus a multi-disciplinary effort, requiring collaboration from the energy sector and the building sector. It is important to note that in terms of reference, the energy sector looks more at deploying clean energy sources to buildings and that the building sector focuses on reducing GHG emissions from the use of electricity within buildings (C40 Cities & McKinsey, 2017).

For the IPCC, cumulative carbon budgets are used as a framework for displaying the relationship between increased carbon emissions and global temperatures and for modelling scenarios into the future (IPCC, 2021). The IPCC has modelled GHG emissions scenarios that indicate increasing temperatures associated with higher cumulative GHG concentrations (IPCC, 2021). The IPCC's 6th Assessment Report (6AR), states in no uncertain terms that the cumulative emissions are required to reach net-zero emissions pathways by 2050 to limit anthropogenic induced climate change (IPCC, 2021).

The definition from the IPCC in terms of looking at historical emissions that have been increasing over time is slightly different from that used by other organisations such as the definition from the WRI or the United Nations Framework Convention on Climate Change's (UNFCCC) 'Race to Zero Campaign'. The latter encourages organisations to set targets for zero emissions (UNFCCC, 2021). In the Race to Zero Campaign, companies are required to achieve zero-emissions by 2050, but not for their historical emissions (UNFCCC, 2021). It will mean emissions will be zero for a specific accounting period/ year and should continue to be on a zero-emissions pathway.

The Green Building Council of South Africa (GBCSA) for example defines a net-zero carbon building as a highly energy-efficient building that is wholly powered from renewable energy sources that is on-site and/or off-site and may include a portion of off-sets that would match the building operation's energy consumption (GBCSA, 2019). This definition is clear that the emissions from a building is a result of the operational activities of the building and do not include embodied emissions.

A net-zero carbon building can also be referred to as a zero-emissions building or a low to zero carbon building. The definition from the South African Green Building Council is largely derived from the Global Green Building Council (WGBC, 2021). Canada introduced a 'Net Zero Emissions Accountability Act' in 2020 where achieving zero emissions targets is made legally binding (Canada, 2020). This Act defines *net-zero emissions* as 'anthropogenic emissions of greenhouse gases into the atmosphere are balanced by anthropogenic removals of greenhouse gases from the atmosphere over a specified period' (Canada, 2020). While the wording differs, the Act is not limited to the context of the building sector and thus the principle of matching and balancing inputs of emissions into the atmosphere with methods and means of removal, so that emissions are zero for a period or project.

The definition used by the World Green Building Council is thus aligned with international organisations and movements and this definition is referenced by many organisations and countries (ARUP, 2019). It is interesting to note that the definition from the IPCC stands alone in its account of cumulative emissions in the definition of net-zero emissions. To achieve safe pathways to the future, it is vital that organisations and nations rally behind the science behind setting targets and ensure that their actions are united in limiting the worst impacts of human-induced climate change.

For new buildings, the concept of historical emissions need not apply, and the definition provided by the GBCSA can work well to save emissions into the future. However, the definitions provided are for both new and existing buildings and so currently, cumulative emissions are not included in the definition of a net-zero carbon building for existing buildings. A net-zero carbon building is designed and engineered to achieve significant GHG emissions reductions over a set period (GBCSA, 2019). The time frame for neutralising the energy consumption by the building through renewable energy and/or off-sets is generally done on an annual basis (GBCSA, 2019). This is important as there may be occasions where the building does emit carbon – this may be due to the intermittencies of renewable energy or seasonal fluctuations in energy demand and is offset by periods of higher carbon removal or off-sets during the period (GBCSA, 2019). With this point, it is understood that the zero-carbon building does not necessarily mean that the building is off the electricity grid. The electricity grid is an important investment as it is an enormous network that allows for electricity to be deployed across the country, which is valuable especially when certain areas experience shortages (GBCSA, 2019). The Grid can also allow for a diverse range of sources of electricity, even when the source of the energy is located far away.

A net-zero carbon building, therefore, is a highly energy-efficient building that obtains almost all, if not all, its power from renewable energy, be it on-site or off-site or by employing off-sets (WGBC, 2021).

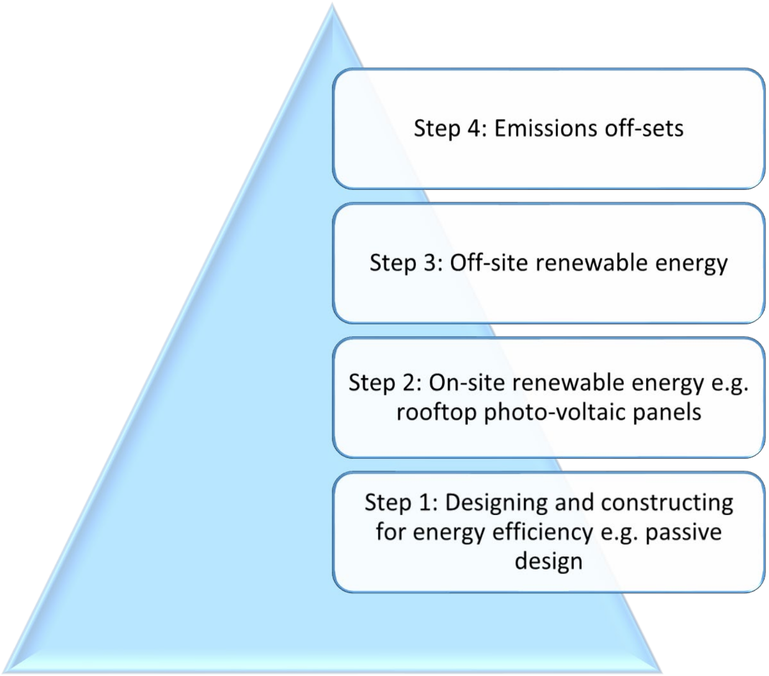


Figure 2: Steps to achieving a low to zero emissions building (GBCSA, 2019).

Net-positive Carbon refers to buildings that have produced more carbon-free energy that is required and have thus in a way made a net positive contribution to the removal of GHG emissions within their environment (GBCSA, 2019). This study will see the use of the term "net-zero carbon". Replacing the term carbon with energy is also used often, with the difference here being that the term "carbon" is adopted as an abbreviation for "carbon equivalent," that is the commonly used metric to describe the global warming potential of the gas emitted - which mainly includes carbon dioxide (CO_2) but also methane (CH_4), nitrous oxide (N_2O), and other gases (IPCC, 2006). The amount of carbon emissions released depends on its source, and there are different conversion factors used to calculate this which are also specific to their geographic location (GPC, 2014). Using an energy-zero terminology can refer to a carbon-zero scenario but in this case, it further narrows down into the translation that the operations of the said application (e.g., a building) do not consume energy at all. The energy that is derived from fossil fuels emits high amounts of carbon, while renewable energy sources for the operations of a system, results in zero carbon emissions.

In environments where the grid is not derived totally from renewable energy, new buildings that aim to be of low to zero carbon profiles have their carbon-based energy consumption reduced as much as possible through building design strategies and technological efficiency measures, following which employs on-site renewable energy generation, and only thereafter through the procurement of off-site renewable energy that is preferably locally produced, and finally with off-sets, if required (WGBC, 2021).

While embodied carbon is of significance as the sector represents at least 11% of global GHG emissions, embodied carbon is not considered under the definition of low to zero carbon buildings, which applies to the operational emissions from buildings (Global ABC, 2018). This figure is widely cited by other organisations such as C40, Architecture 2030, and ICLEI (C40 Cities, 2019a; Architecture2030, 2021; ICLEI, 2018).

2.1.4 Drivers and trends for energy consumption in the building sector

Energy usage in the building sector can be influenced by three trends, namely technological and design inputs, weather and climate, and policy direction (WEC, 2004). Forces that would stimulate the consumption of energy within buildings can be referred to as drivers of energy usage, and over periods of time, these drivers can show trends in the usage of energy (WEC, 2004).

As energy usage comes with a cost, its consumption alone motivates a need to measure and manage usage - thus conserving overhead costs. The design of a building as per the first principles of architecture, passive design, can significantly reduce the structural energy demands of the building, and ensuring that active energy systems are efficient will reduce the energy usage of equipment such as heating and cooling (SEA, 2016). The design of a building also influences the energy usage of a building in ways of allowing for natural sunlight thus reducing the need for lighting and where designing for appropriate ventilation reduces the need for space cooling (SEA, 2016).

The building sector encompasses a diverse use of energy-intensive technologies that varies per sub-sector such as lighting and thermal comfort in office buildings, then lighting and Heating, Ventilation, and Air-Conditioning (HVAC) in retail setups (OECD, 2016). Energy consumption due to heating and cooling requirements in buildings contributed to a fifth of the increase in global energy demand in 2018 (IEA, 2019). In addition to structural design, the energy efficiency of equipment can further impact the energy usage of a building. Global statistics show that lighting accounts for 20% of global electricity consumption and is often described as 'quick-win' for energy efficiency in buildings (SEA, 2016).

The International Energy Agency (IEA) was formed in 1975 and is one of the central multilateral organizations for energy-importing countries and their compilation of global statistics is largely used around the world (Graaf, 2012). The IEA is central to energy governance, with its annual publications on energy perspectives being used by policy-makers and researchers around the world (Ibrahim, 2020). This section will discuss the drivers and trends of energy use in buildings while highlighting the unique global perspectives on energy-use produced by the IEA.

Since 2009, technological improvements in energy efficiency and renewable energy technologies have increased significantly and the costs have since decreased, especially for photovoltaic panels, yet the uptake of energy efficiency interventions has been slow (IEA, 2019). Notwithstanding that the world has made much progress in terms of energy efficiency technologies, the global energy intensity of the global economy is influenced by many drivers. Currently, the world's economy is largely correlated with energy use - an increase in economic growth has broad implications for energy use (IEA, 2019). As such the global energy intensity is a term that describes the annual performance of the world's primary energy production against the global GDP (WEC, 2004). Figure 3 presents actual percentage improvements in global energy intensities until 2018, with 2018 seeing a 1.2% improvement in energy intensity (IEA, 2019). Energy intensity is a useful gauge on how the global economy uses energy resources and includes coal-based energy resources, diesel, and petroleum use amongst others (IEA, 2019). Research suggests that global primary energy intensities can improve an average of 3% each year and should this improvement had been achieved from 2015 to 2018, it would have equated to a saving of USD 4 trillion (IEA, 2019). This research is based on the premise that reducing demand for resources means less cost incurred for resources that can be avoided through improving efficiencies.

Energy intensities may also be used in specific actions such as in reducing the electricity usage per meter square of a building. In a similar way, improving energy intensities in buildings can result in improving expenditure per meter square of a building. There is an economic benefit to investing in energy efficiency and from the full life cycle of constructing net-zero carbon buildings (GBCSA, 2019). Resources such as energy (or electricity) represent a cost to the end-user, be it an individual, organisation or city, and improvements in energy efficiency reduce these costs whilst offering a long-lasting investment (Architecture2030, 2021). Studies have shown that improvements in energy efficiency or the conservation of energy have a greater cost reduction than installing more energy capacity onto a power plant (C40 Cities, 2019a). While there may be a higher initial cost in constructing a net-zero carbon building compared to a standard building, the life cycle costs of a net-zero carbon building are far lower (GBCSA, 2019).

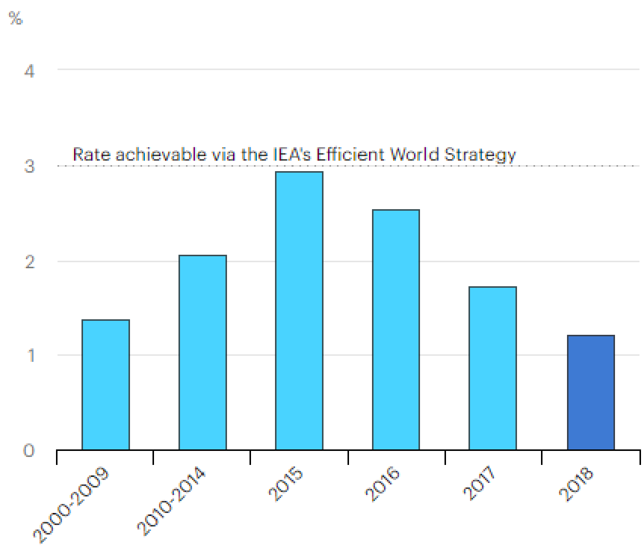


Figure 3: Global improvements in primary energy intensity 2000- 2018 (IEA, 2019).

However, while energy intensities are largely decreasing, the rate at which they are decreasing is slowing down and this includes the building sector displaying dwindling improvements in energy intensities since 2015 (IEA, 2019). Energy use is associated with the economy, and it has been shown that economic growth results in sluggish improvements in energy intensity (IEA, 2019). An increase in economic growth potentially relates to an increase in demand for more energy-consuming goods, where an increase in consumer durable goods such as motor vehicles can also see a rise in the shift to singular passenger vehicles as a mode of transport (SEA, 2016). There may also be a rise in the demand for floor area per person in buildings which will increase the energy usage and energy intensities within buildings (IEA, 2019). Within subsectors of the buildings sector, energy usage shows distinct profiles, and interestingly, in the residential sector, the energy usage of dwellings varies depending on the building owners' income levels.

As such, in describing the energy profile of buildings, using sub-sectors of residential and commercial can provide general ideas of how the building will consume energy (SANEDI, 2021). A distinction is made between new buildings and existing buildings due to significant technical and financial differences between constructing buildings as energy efficient and then retrofitting an existing building to improve energy efficiency. The residential sub-sectors can be further disaggregated as per level of affluence while commercial sector is based on its application (SANEDI, 2021).

Buildings within the residential sub-sector can be described into 9 categories that include High Income – Houses and Apartments, High-Middle Income – Houses and Apartments, Low-Middle Income – Houses and Apartments, Low Income – Houses and Apartments and Informal Houses (SANEDI, 2021).

For buildings within the commercial sub-sector, categories are based on the use of the building because the use of energy-intensive technologies would vary such as lighting and thermal comfort in office buildings, and lighting and HVAC in retail setups. These categories include Retail, Office, Hospital, Hotel, and Warehouse (SANEDI, 2021). Energy consumption will vary per category and so will intended strategies for energy efficiency.

In addition to economic growth, the main drivers of energy use in buildings include population growth, cost of energy, the uptake of efficient energy equipment, weather and climate, and importantly - the regulatory environment (SEA, 2016). A review of international policies by Sustainable Energy Africa (2016) shows that of the most successful and important tools for Energy Efficiency (EE) is in implementing building codes (SEA, 2016).

Weather and climate are important factors in energy-use and it is anticipated that thermal comfort will become a major driver of energy usage in buildings (WEC, 2004). Warmer than usual temperatures during the summer months and colder winters will fuel the usage of air-conditioners and heating equipment and as such the IEA recorded this influence during the USA's 2018 summer (IEA, 2019). It is highly likely that climate change may result in weather extremes and contribute to an increase in the use of HVAC equipment, should efficient building design and technologies not be adopted (WMO, 2021). Global sales figures have indicated that inefficient cooling technologies are still being procured and where renewable energy alternatives such as solar water heaters and efficient technologies like heat pumps only contributed to 10% of total sales in 2018, with conventional and non-renewable energy sources comprising the majority of the remaining sales (IEA, 2019). It is important to understand what influences investment and procurement of older, inefficient technologies as this means higher GHG emissions compared to new and more efficient technologies for the life cycle of the technology, along with an increase in lifecycle costs.

It is also apparent that the energy intensity for Latin America has largely remained the same, with some fluctuations. Economic growth and development from emerging economies are adding to the rising demand for energy, where policies do not adequately address energy efficiency and energy usage within buildings (IEA, 2019). This publication from the IEA provides useful information yet it is uncertain as to whether data received from all regions are representative of the full landscape of the building sector using South Africa as an example, the data from buildings in terms of floor area and size and energy usage is not comprehensive.

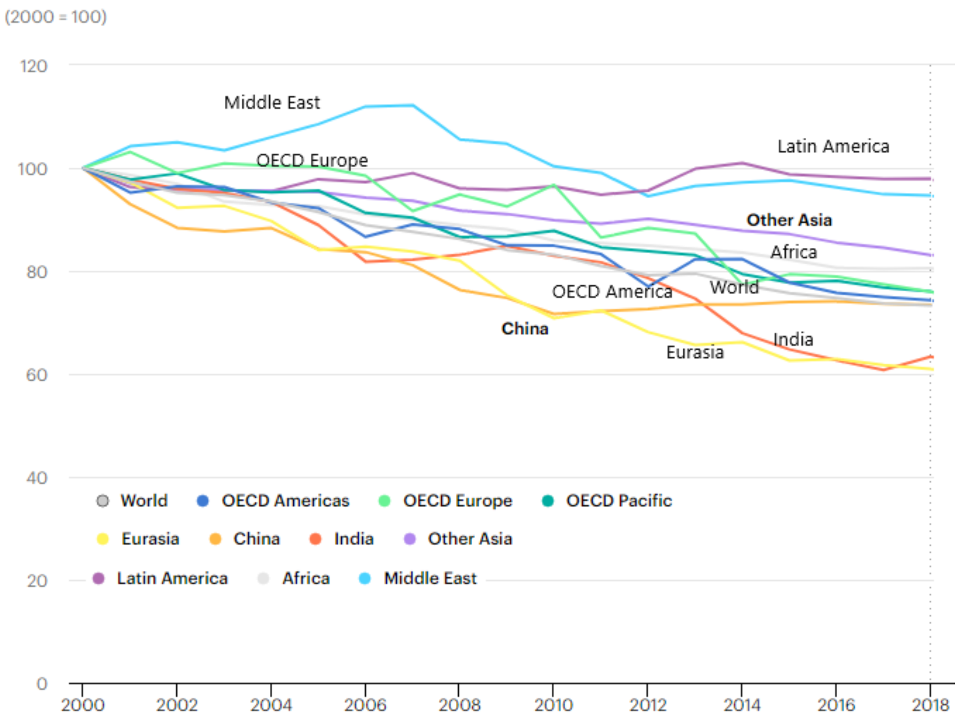


Figure 4: Buildings sector energy intensity in selected regions 2000-2018 (IEA, 2019).

In 2018, South Africa's Department of Minerals and Energy released draft regulations for mandatory display and submission of energy performance certificates for buildings and details the requirements for this submission in SANS 1544 (DOE, 2018). This draft regulation has yet to be gazetted and will apply to all buildings over 2000m^2 and all public buildings over 1000m^2 (DOE, 2018). Part of the objective of this regulation is to maintain a register of the energy performance of buildings in South Africa which may support and influence the management of energy consumption from the building sector in the future.

The IEA reports that two-thirds of countries do not have mandatory energy efficiency codes for buildings and that this could be part of the reason for the slowdown in energy efficiency results within buildings (IEA, 2019). The regulatory environment is an important influence in the uptake and adoption of energy efficiency practices and provides direction for local authorities and best practices for the private sector (WEC, 2004). Due to the rapidly expanding energy efficiency and renewable energy market, policy-makers would need to update policies and energy efficiency requirements in order to adapt to market changes and improvements in energy efficiency technologies that could see economies saving trillions through reduced expenditure on energy demands (WEC, 2004). This is an apt account of updating efficiency policies within the building sector and for other rapidly growing technologies. Keeping up with the level of energy efficiency gains in the sector is vital as energy efficiency achievements in the building sector become more difficult to achieve in the long-term (SANEDI, 2021). 'Quick-wins' often means that energy efficiency improvements are of the first interventions that many organisations take, yet is equally as important to understand the complete scope of energy efficiency gains that could be implemented so that maximum cost-savings are to be achieved over a longer period (SEA, 2016).

The building sector can be described as one that is integral to people's safety and living (C40 Cities, 2019a). Whether it is a luxury home, a first home, a retail outlet, or a supermarket – investments into the safety, comfort, and varying degrees of aesthetics for buildings is inevitable. It is important to keep abreast of the trends and their implications of energy consumption across the sectors so that long-term plans for energy efficiency can be set out (WEC, 2004). Buildings as structures may last for almost a hundred years, but people's behaviours and demands are not as rigid (C40 Cities, 2019a). Considerations into strategies and policy developments should be forward-thinking and flexible to include investments that are durable and resource-efficient.

2.2 Contextualising the building sector within the eThekwini Municipality

2.2.1 A South African context to reducing GHGs in the building sector

South Africa's Constitution defends and upholds the fundamental rights of its citizens, and specifically refers to the right of every South African to an environment that is not harmful to his or her health and/ or well-being and further calls for the protection of the environment against pollutants and degradation. The National Climate Change Response White Paper guides the country's climate change plan and recommends the employment of an 'optimal mix' of mitigation strategies that can achieve the required emissions reductions while promoting job creation and the green economy (DEA, 2012). Section 8.4 of the National Climate Change Response identifies the regulation of commercial and residential building standards to enforce green construction practices (DEA, 2012). In South Africa, there is a comprehensive set of standards and guidelines for the construction of new buildings that are prescribed by the South African National Standards (SANS 10400), wherein contains energy efficiency requirements since 2011 listed in part XA of the regulations (DTI, 2011). The regulation clearly states that the motivation for these energy efficiency requirements is the reduction of GHG emissions in efforts of mitigating climate change. Furthermore, the objective of achieving a zero-emissions context is included in the National Development Plan in Chapter Five: Zero-emission Building Standards by 2030 (NDP, 2011).

In 2017 South Africa's absolute CO_2 emissions generation totalled 452 $MtCO_2$, ranking South Africa 14th in the world in terms of contribution to global greenhouse gas emissions (WEF, 2019). The majority of GHG emissions both globally and locally are produced from the use of energy that is derived from fossil fuels. Energy consumption can broadly be categorised into two aspects, namely transportation and stationary applications (GPC, 2014). Energy usage from stationary applications such as buildings is largely from electricity, and in South Africa, about 93% of electricity is sourced from coal (EIA, 2015).

South Africa is a party to the United Nations Framework Convention on Climate Change (UNFCCC) 1992, the Kyoto Protocol 1997, and most recently the Paris Agreement of 2016. South Africa in 2016 approved its Nationally Determined Contribution (NDC) as per the terms of the Paris Agreement and this refers to the country's projected GHG emissions based on the country implementing a suite of mitigation programmes (DEA, 2015). South Africa's NDC guides the country towards a peak, plateau, and decline emissions trajectory range that includes land use, land-use change and forestry (LULUCF) to between 398 and 614 $MtCO_2e$ over the period 2025–2030 and has since updated these targets in March 2021 (RSA, 2021). The country's NDC was revised in 2021 and was approved by Cabinet in September 2021 (RSA, 2021). However, Climate Action Tracker (CAT) rates the INDC targets as "Highly insufficient" with CAT's projection for South Africa's emissions trajectory under its implemented policies in 2020 and 2030 are expected to increase by 75% and 93%, respectively, on 1990 levels excl. LULUCF (CAT, 2021).

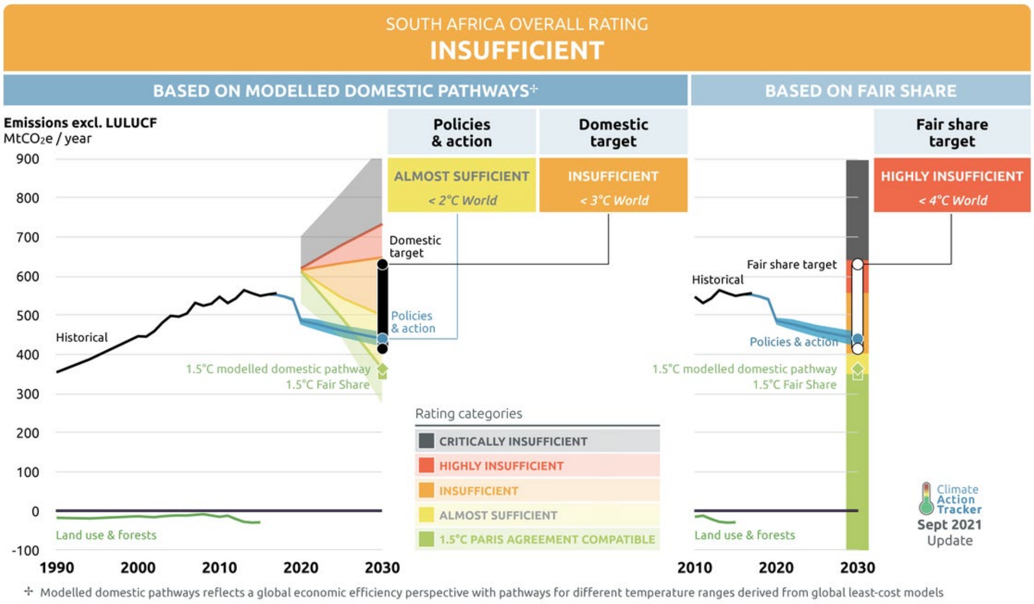


Figure 5: Assessment of South Africa's emissions scenarios (CAT, 2021).

South Africa is still at a developing country status and has one of the highest levels of inequality in the world. High levels of inequality is associated with poor growth and civil unrest, and such issues may make forward climate planning more difficult to prioritise (OECD, 2015). Nevertheless, South Africa has adopted numerous measures to address climate change issues, having ratified the Paris Agreement and signing in a carbon tax legislation for high GHG emitters. Energy efficiency has also been noted as a key priority of South Africa, due to resources constraints and challenges in the national supply of electricity (DTI, 2011). The advocacy of switching to renewable energy from the private sector is further motivated by a need to diversify their energy sources and reduce reliance on a constrained grid. This resulted in a significant shift to energy-efficient appliances used within residential, commercial, and industrial buildings (SANEDI, 2021).

It is modelled that collectively, buildings within South Africa, also referred to as the ‘building sector’ which includes residential, commercial, and institutional buildings, could offer GHG reductions of about 45% by 2050 relative to the sector’s business-as-usual reference projections (DEA, 2016). A heavy reliance on coal means that emissions from electricity usage is significant, and the building sector in South Africa is dependant largely on the electricity grid for its lighting, equipment, and heating and cooling needs (EIA, 2015). Developing countries can largely expect that their contribution of new building stock will continue to grow in the near future. Globally, the floor area is projected to double by 2050 with emerging economies contributing the most of the build (Architecture2030, 2021). South Africa will indeed see growth in development and this contributes to the building sector having such a large mitigation potential (WBCSD, 2018). Notwithstanding the fact that the GHG emissions projection only arise from the operations of the building, other environmental impacts are linked to processes of resource extraction from the construction sector. South Africa’s Council for Scientific and Industrial and Research (CSIR) estimates that building and construction activities account for 50% of all non-renewable materials extracted from South Africa’s earth (Davis-Reddy & Vincent, 2017). Challenges experienced in the construction sector, such as resource scarcity, could impact the development of new buildings.

New buildings are perhaps targeted due to its relative ease of implementing GHG reduction interventions compared to existing buildings. A building that is designed and constructed to be as efficient as possible is less consuming of finances and technical aptitude in comparison to existing buildings. Nonetheless, existing buildings should not be neglected in the consideration of energy efficiency investments and interventions and this study will explore the GHG reduction potentials of new and existing buildings as subsectors within the building sector, with a focus on achieving goals of carbon neutrality for new buildings from 2030, and all existing buildings by 2050 (Architecture2030, 2021).

Environmental protection requires a balance with the need for economic development, especially in a developing country context that suffers from severe levels of inequality (DEA, 2016). As such, South African cities are faced with the challenge of creating a balance between the utilisation of its natural environment in a way that addresses past economic and social injustices.

In line with reducing GHGs, South African policies and strategies have identified the building sector as a key focus area for GHG reductions but the uptake of green buildings has been slow and of net-zero carbon buildings even slower (EThekwini, 2021). In addition to climate change mitigation benefits, the building sector has the potential to improve upon the resilience and overall resource efficiency of cities. With efforts such as harvesting of rainwater from building rooftops for consumption to reduce demand on natural resources and by employing green roofs or permeable paving, buildings can offer support to aging municipal infrastructure cope with the growing demands of storm-water management and also to conserve precious energy and water resources, especially in water-scarce countries like South Africa (EThekwini, 2021).

While this study only focuses on climate change mitigation interventions, these are some examples of resilience solutions that buildings can offer.

2.2.2 An overview of the eThekwini Municipality

In South Africa, the eThekwini Municipality contributes 5% of the country's total GHG emissions, responsible for tCO_2e 29,025,638 (ETH, 2017). The eThekwini Municipality has been categorised as an "Early Peak" typology city by C40 Cities. This indicates that the eThekwini Municipality has a developmental status that stifles ambitious climate action while still producing higher than average emissions than the average of cities within the C40 network (C40 and ARUP, 2016). "Early Peak" city typologies refer to those that have higher than average emissions per capita and while urgent action is required to curb emissions, the city's development and economic status limit this. Cities in this category require a peaking of emissions sooner rather than later in order to avoid further emissions, but the developmental status of the city means a reduction in emissions cannot be immediate. Developmental challenges within eThekwini amongst others include a 0.65 GINI coefficient, with unemployment levels at about 30% (EThekwini, 2016). Other examples of cities in this range include the City of Cape Town, the City of Johannesburg, and the City of Tshwane (C40 and ARUP, 2016).

In addition to the contribution of GHGs into the atmosphere, the eThekwini Municipality is particularly vulnerable to the impacts of climate change. According to the Durban Climate Change Strategy, a few of the impacts that the eThekwini Municipality will experience includes;

- A projected increase in frequency and intensity of rainfall, which could disrupt the supply of water and the quality thereof
- Increase in frequency of heat waves and
- Rising sea levels (EThekwini, 2016).

Addressing these risks from climate change will require urgent action from the eThekwini Municipality and its stakeholders. The eThekwini Municipality, to meet their target of being "the most liveable and caring city in Africa," will need to ensure a safe and healthy city of her residents, while enhancing residents' quality of life and resilience (EThekwini, 2016). Notably, the projected increase in extreme rainfall events gave rise to significant damage to public and private infrastructure, namely during the 2017 storms that cost the eThekwini Municipality over R650 million to repair damaged infrastructure and during the Easter 2018 storms where 80 residents lost their lives (EThekwini, 2021).

The eThekwini Municipality will need to revise current business-as-usual ways of the economy such as developing transport systems and buildings so that it may achieve the emissions reductions that are required by science.

It must be noted that approaches to analysing GHG emissions may differ per economic region and looking at a sectoral perspective that is based on emissions from its end-use allocations can paint a very interesting picture of where efficiencies can be achieved. From a sectoral perspective, transport and building activities makeup of the largest contributors to the 70% of global GHGs that cities add to (C40 Cities, 2017).

When accounting for emissions from electricity, the building sector represents 34% of eThekwini Municipality's GHG emissions and this is largely comprised of residential and commercial buildings (C40 Cities, 2019b). Based on this and the huge potential for mitigation of GHGs within the sector, the eThekwini Municipality has prioritised the building sector as one of the ‘low-hanging fruit’ for reducing significant future greenhouse gas emissions in the city, and especially new buildings.

Given these priorities, the development of mitigation potentials within sectors of the eThekwini Municipality would be critical to informing a practical and affordable way forward for the city in implementing impactful climate change mitigation projects.

2.3 Review of Methods and Approaches to Estimating GHGs within cities

2.3.1 Approaches to the analysis of mitigation potentials

Mitigation potential refers to the quantified potential to mitigate GHGs over specific timelines. Mitigation potential is calculated as the difference in GHGs from a baseline or business-as-usual future where little emissions reductions occur and from a future with enhanced emissions reductions (IPCC, 2006). The projection of GHGs into the future can be achieved through the use of models that would firstly project future GHGs using the baseline scenario and then with a low emissions scenario (Le Quéré *et al*, 2016). It is important that a credible baseline inventory be established. Mitigation potential assessments require extensive analyses of baseline inventories and then modelling a series of future emissions trajectories constructed on a growth rate that is without any emissions reduction interventions (baseline case) and where the projections are based on estimated population and economic growth (DEA, 2016). The low emissions scenarios can include more than one trajectory with differing levels of interventions that would reduce emissions. The data inputs require establishing the detail within scenarios that would describe the GHG reducing interventions, and its projected applicability and market uptake of intervention within its sector (DEA, 2016).

The way in which a city reports on and classifies its GHG emissions is critical to the effective usage of the data. The reporting method for GHG inventories may reflect various perspectives and look at a sectoral perspective that is based on emissions from its end-use allocations can paint a very interesting picture of where efficiencies can be achieved.

It is also important that cities around the world ensure a degree of consistency to allow for ease of understanding and comparison. The Greenhouse Gas Protocol, which stems from collective efforts from C40, ICLEI, the Joint Work Program of the Cities Alliance between the World Bank, UNEP, and UN-HABITAT, sets out guidelines for completing GHG emissions inventories within cities (GPC, 2014). There are two required approaches for GHG emissions reporting at a city-level from the GHG Protocol and that is the a) scopes framework and the b) city-induced framework (GPC, 2014). The scopes framework categorises GHG emissions according to operational boundaries of the city because emissions resulting from city inhabitants and activities may be produced within city boundaries as well as outside its boundaries (GPC, 2014). The city-induced framework refers to the accounting of emissions used by sectors across scopes 1, 2, and 3 within the city, with the robustness of accounting classified into levels i.e., BASIC and BASIC + levels (GPC, 2014). Using the BASIC level for reporting GHG emissions, a city would cover end-use emissions from stationary energy (includes buildings, energy supply), transportation, and waste, while the BASIC + level includes the reporting of emissions from Agriculture, Forestry, & Other Land-use (AFLOU) and Industrial Processes and Product Use (IPPU), among other transboundary emissions (GPC, 2014). The BASIC + level of reporting is also aligned to the IPCC Guidelines for National Greenhouse Gas Inventories (IPCC, 2007). Using a sectoral approach, considerations should be given to selecting sectors that have a substantial impact on the contribution of GHG emissions and even its removal (IPCC, 2007).

Once the sectors and their emissions baselines have been established, approaches to determine the mitigation potential of the sectors can be applied. Additional data is also required such as gross domestic product (GDP) and population growth rates.

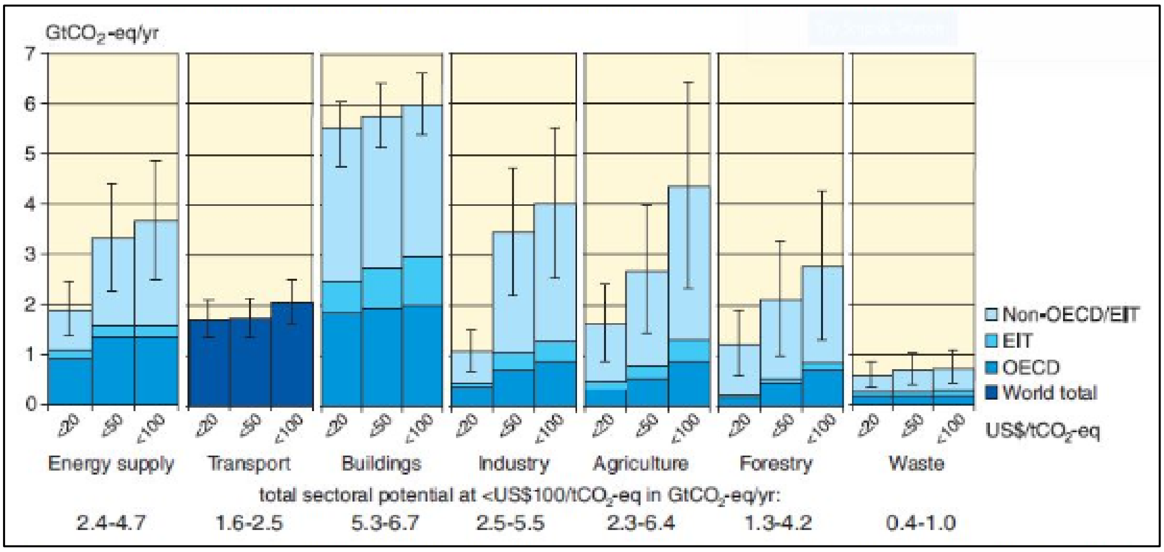
Mitigation potential assessments involve rigorous sets of analyses to project the amount of GHG reductions that could potentially be achieved at a future date. A business as usual (or without any interventions) model of emissions is developed, with projections based on estimated population and economic growth (Ekins et al, 2011). The mitigation potential of a sector could be modelled by combining the following influences (DEA, 2016):

1. Technical Potential
   This approach explores the potential reductions in GHG emissions through interventions based on existing and available technologies
2. Economic Potential
   Understanding the potential GHG reductions and the associated costs through cost-benefit analyses and
3. Market Potential
   Analysing the potential of the market that would adopt a GHG reducing intervention or technology that is vital to projecting future emissions.

Top-down and bottom-up approaches used in mitigation potential assessments are similar to technical, economic, and market potential approaches employed in South Africa's Mitigation Potential Assessments. Top-down and bottom-up approaches involves robust analyses to be conducted on establishing scenarios that include GHG reducing interventions and projections on the potential market uptake of the sector to the specific GHG reduction measure (IPCC, 2007). Bottom-up approaches refer to the assessment of mitigation options, based on granular activities within sectors and assume an unchanging macro-economy while top-down approaches look at aggregated regional-wide data using factors from the macro-economic potential of the various GHG mitigation pathways (Ekins *et al*, 2011). However, a hybrid of these approaches is recommended for a more calibrated model and has been considered since the TAR publications by the IPCC in 2001 (IPCC-TAR, 2001). It must be noted that while any model would benefit from more input data, it then becomes increasingly important to transparently display the scope and limitations of the modelled outcomes (Ekins *et al*, 2011).

In its 4th Assessment Report, the IPCC produced an estimation of regional and sectoral economic mitigation potentials that is visualised as a histogram showing the ranges of abatement potentials and costs (IPCC, 2007). Figure 6 from the IPCC shows through a MACC a comparative analysis of the economic mitigation potential of sectors per regions of the world, using a bottom-up approach and accounts for technical interventions and does not consider interventions based on behavioural changes (IPCC, 2007).

Sectoral emissions refer to 'end-use allocations' of emissions, which means that the emissions for buildings are largely from electricity use as emissions are attributed to the end-use sector and not to the energy supply sector (IPCC, 2007). However, the analysis only includes the bottom-line cost of sectoral abatement but does not account for social costs and benefits and 'social discount rates' (IPCC, 2007). In the context of climate change, social discount rates are extremely important as these factors in the costs of unmitigated future threats from climate change (Sink, 2010).



In reading the graph, the vertical range lines display the assessed ranges for global economic

Figure 6: Estimated economic potential by sector and region in 2030 (IPCC, 2007).

potentials in each sector (IPCC, 2007). The recommendations for reporting on sectoral perspectives for countries are contained within the IPCC Guidelines for National Greenhouse Gas Inventories. This is also aligned to the BASIC + methods of GHG accounting within cities as per the GHG Protocol reporting guidelines (GPC, 2014).

An interesting outcome of this assessment is the indication that buildings will offer the most amount of GHG reductions at the lowest cost at a global level. However, it is noted within the IPCC's 4AR that the costs for the assessment are time-specific and that a change in the baseline scenarios will impact mitigation potentials and costs (IPCC, 2007). Baseline scenarios may further change with improvements in data and data collection systems.

More recently, a publication from the World Resources Institute in 2016 also highlighted the building sector as the least cost method to reduce GHGs and was based on the data contained from the IPCC's 4th Assessment Report and accounted for indirect emissions from electricity (scope 2) that is generally allocated to energy supply sectors (WRI, 2016).

The indications of Figure 7 are that the global building sector offers the highest GHG abatement (or mitigation) potential at the least cost, with over 90% of mitigation interventions shown as 'low cost' emissions.

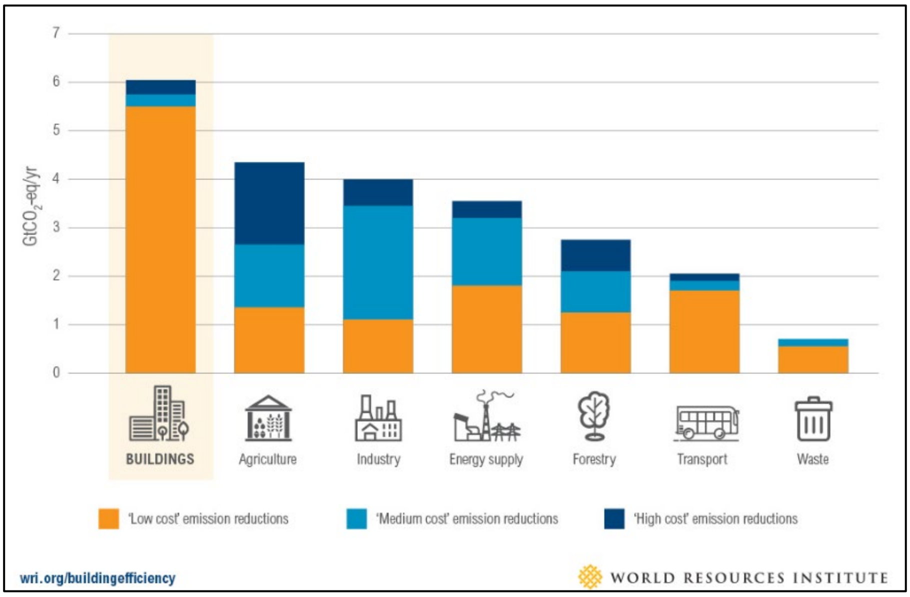


Figure 7: A sectoral representation of mitigation potential and associated costs ranges for 2030 (WRI, 2016).

The visualisation of the data in Figure 7, further highlights the importance of quantifying the mitigation potentials and subsequently, the MACC curves for sectors and sub-sectors of an economy, as these are key to informing decision-making processes on climate change mitigation. Many cities around the world are conducting MACCs as a tool to aid in identifying both immediate and long-term strategies and plans to stimulate and aid in the transition to a low carbon economy.

In 2007, South Africa produced the Long-Term Mitigation Scenarios that determined a pathway for GHG emissions reductions based on "Growth Without Constraints" and a "Required by Science" scenarios (LTMS, 2007). Further "action-based" pathways were configured that were based on interventions that could realistically and feasibly occur in the country (LTMS, 2007). South Africa's Department of Environmental Affairs, now known as the Department of Environment, Forestry, and Fisheries, developed a task team to select key sectors that would be part of the national mitigation potential analyses (DEA, 2016).

South Africa published the country's first series of Mitigation Potential Analyses in 2016 and is set to continually update these analyses (DEA, 2016). As there is significant focus on the building sector, both internationally and locally within the eThekwini Municipality, it would be beneficial to produce a marginal abatement cost curve for the eThekwini Municipality to add to the existing evidence base for decision-making and taking action to reduce GHG emissions.

In addressing the opening objectives of this study, existing research was utilised on the mitigation potential of high emitting sectors within the eThekwini Municipality conducted by the C40 Climate Action Plan as part of a partnership between C40 and the eThekwini Municipality to develop a Climate Action Plan for the city (C40 Cities, 2019b). The MACC takes the assessed mitigation potential analyses and further quantifies the cost of reducing GHGs per intervention.

As part of the C40 Mitigation Pathways assessment, a detailed model was produced in which emissions growth scenarios within various sectors have been modelled until 2050. Growth factors used in the Climate Action Plan for the eThekwini Municipality (hereafter referred to as the 'CAP') were based on population and economic growth assumptions to inform future changes in the sectors analysed. Gross Domestic Product (GDP) per capita was used in the CAP as an indicator for economic growth, and while it is acknowledged that this measure should not be solely used to make deductions about the state of a nation, it is a relatively simple indication of real and inflation-adjusted growth for sectors within an economy (C40 Cities, 2019b). The emissions growth projections contained within the CAP are built on the 2015 baseline of emissions provided by the eThekwini Municipality's GHG accounting team that uses guidelines for GHG reporting from the Greenhouse Gas Protocol (GHG Protocol) (ETH, 2017). The GHG Protocol for cities currently requires two reporting standards for GHG emissions from cities, where the first approach categorises emissions into "scopes" that indicate the location of the emissions source in relation to the reporting city, and the other looks at emissions per sector activities (GPC, 2014). This protocol is adhered to by the eThekwini Municipality in their GHG inventories and the C40 Mitigation Pathways for eThekwini and as such, this project thus uses this approach in order to ensure consistency. In this regard, the focus remains on emissions from a sectoral perspective where emissions are allocated to the end-user as opposed to the energy supply sector.

Sectors covered within the C40 Mitigation Pathway align with the GHG Protocol's BASIC level of reporting with the addition of the industrial processes sector. The GHG accounting team within the eThekwini Municipality also employs the BASIC level of reporting. Thus, the sectors assessed include; electricity generation, industrial energy, transportation, and waste.

100% renewables	Emission source	Scope	BASIC	BASIC+
	Stationary fuel combustion	1	✓	✓
	In-boundary transportation	1	✓	✓
	Grid-supplied electricity	2	✓	✓
	Waste and wastewater generated and disposed in the city	1	✓	✓
	Waste and wastewater generated in the city and disposed outside	3	✓	✓
	Electricity transmission and distribution losses	3	×	✓
	Out-of-boundary transportation	3	×	✓
	Industrial Processes and Product Use (IPPU)	1	×	✓
	Agriculture, Forestry, Land Use (AFOLU)	1	×	✓

Figure 8: Tabled summary of the differences in reporting methods as per GHG Protocol (Albert, 2019).

The BASIC+ level of reporting accounts for a wider range of emission sources, and to qualify, all scope 1, 2, and 3 emissions should be assessed within the Municipality under this methodology. As displayed in summary in Figure 8, scope 3 emissions refer to emissions that might occur outside the City's boundary but also apply to both the upstream and downstream flows of each category (Albert, 2019). The BASIC + level of reporting from the GHG Protocol involves collecting data from sectors that are often very difficult for cities such as agriculture, forestry, and other land use (AFLOU) and industrial processes and product use (IPPU) that are contained within the scope 1 (GPC, 2014). To account for this and gather this data annually is widely known as a big challenge, especially from sources within the industrial sector (Albert, 2019).

Figure 9 displays a breakdown of the eThekwini Municipality's GHG inventory per sector and is aligned to the BASIC reporting methodology from the GHG Protocol as it excludes the IPPU and AFLOU categories and accounts for all waste (including wastewater), stationary fuel combustion (industrial energy and fugitive emissions), grid-supplied electricity (buildings), and transportation emissions sources within its jurisdiction (C40 Cities, 2019b).

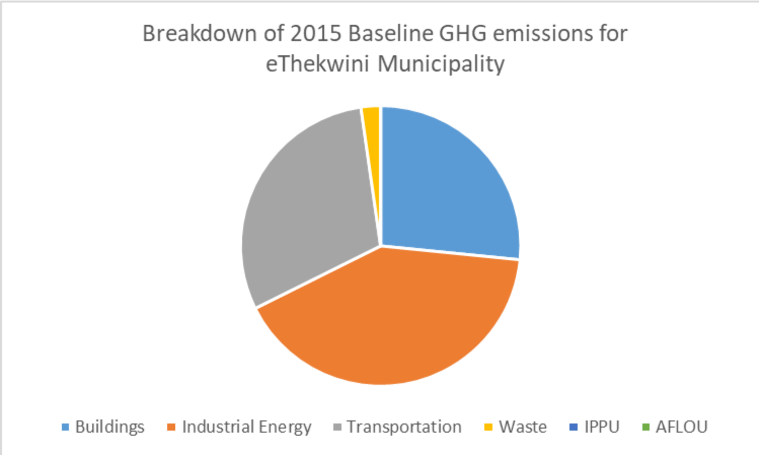


Figure 9: Breakdown of 2015 baseline GHG emissions by sector - eThekwini Municipality (C40 Cities, 2019b).

It is a reality that stakeholders and decision-makers still require to quantify and understand the payback period of GHG-reducing measures. This emphasizes the need to create a MACC – i.e., to model the sectoral mitigation abatement potentials and their associated costs, specific to the eThekwini Municipality, in order to add to the evidence base required when prioritising investments into climate change mitigation efforts. The approach for the MACC will be a combination of assessments onto the technical and economic potential for GHG mitigation, with considerations given to the market potential or sector uptake of the technical mitigation potential. Using a bottom-up approach within evaluating the technical mitigation potential will see the model based on already existing and proven GHG-reducing measures while considering the sectoral uptake of the said measure in a changing macro-economy. The technical potential model will not consider interventions based on behavioural changes. Due to the magnitude of such a complex assessment, the scope of assessing the economic potential will be narrowed to the financial bottom-line costs of the intervention i.e., the capital and operation and maintenance costs, with no consideration given to social costs and benefits and social discount rates. It would be invaluable to consider the social costs and benefits such as job creation, and the quantification of the social discount costs which are the costs of future risks and threats to the eThekwini Municipality.

The MACC developed for this study is intended to be used as part of an array of evidence that would inform effective investment into long-term and workable climate change mitigation programmes. As municipalities have the authority to self-govern, there is an opportunity for the eThekwini Municipality to serve as best practice taking appropriate climate action in a developing city context, and in turn may benefit when unlocking access to financing, and in optimising service delivery offerings to inhabitants at lower operating and administrative costs.

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The future is a zero-carbon building sector – perspectives from Durban, South Africa

Abstract

The built environment is a critical part of the climate change problem in cities and urban buildings can act as a scaled response to mitigating anthropogenic climate change. Buildings may also act as a scaled solution to improving urban resilience in the face of growing populations and impending pressures from climate change such as extreme weather events. Erecting structures and buildings that are resilient to future climate pressures will provide cities with a healthier and safer environment for urban dwellers. Buildings as structures last for well beyond a hundred years, and therefore constructing these buildings to be net-zero carbon from the on-set will ensure that the building stock of the future is a low carbon one. The role of the building sector toward reducing greenhouse gas (GHG) emissions is now better understood, resulting in various initiatives globally, to move toward being a net-zero carbon sector. The eThekwini Municipality (Durban) in South Africa has a long history of developing early climate change interventions and is committed to a zero-carbon building sector. The objective of this research is to provide an assessment of the costs in achieving the emissions-reduction potential for each high-emitting sector in the eThekwini Municipality through the determination of a Marginal Abatement Cost Curve (MACC). The MACC was developed for 2030, 2040, 2050 across key sectors and highlights that the building sector offers significant GHG reductions at the lowest cost when compared to other high emitting sectors. Sectors covered in this assessment align with the approach used by the eThekwini Municipality, employing the GHG Protocol's BASIC level of reporting that excludes the Agriculture, Forestry, & Other Land-use (AFLOU) and Industrial Processes and Product Use (IPPU) sectors. It was found that the building sector offers the lowest cost to mitigate each ton of GHGs when compared to other sectors in the eThekwini Municipality. Several interventions within the building sector further display negative costs, meaning that the intervention will have a positive payback period throughout its lifecycle. The MACC produced in this study is the first of its kind for any municipality in South Africa and will provide insights into the net cost of interventions, already identified by the Municipality, that would mitigate a tonne of carbon emissions. The MACC developed would thus benefit authorities in prioritising actions in addressing climate change within the building sector. This paper brings forward energy efficiency as a vital component to reducing climate change, as energy efficiency interventions in buildings offer substantial mitigation potential within the most feasible payback periods when compared to other sectors.

1 Introduction

Cities are home to 55% of the world's population and could face the worst risks from climate change[1] with many of the key and emerging global climate risks being concentrated in urban centres. Cities will be threatened by an unprecedented changing climate[2] whilst the growing populations and development within these cities are likely to contribute to increased levels of greenhouse gas (GHG) emissions in the atmosphere.[2]

The building sector is one of the largest contributors to GHG emissions, largely through its energy use where it accounts for around a third of global energy use.[3] It is estimated that the building sector contributes 28% of global GHG emissions, with a further 11% of emissions arising from the accounting and consideration of embodied emissions from building materials and construction activities.[4] The building sector is recognised in the IPCC's 4th Assessment Report[5] as displaying a substantial potential for climate change mitigation into the future.

Given that buildings generally have a life span that can range from 40 to over 100 years[4] reducing the output of carbon emissions of a building from the onset, can offer emissions savings throughout its lifespan, providing substantial GHG emissions reductions at the least costs relative to other sectors.[5]

Increasingly there is focus placed on transitioning toward low to zero carbon buildings. In South Africa, four cities namely, the eThekwini Municipality, the City of Cape Town, the City of Johannesburg, and the City of Tshwane have made public declarations through the C40 platform, alongside a number of developed country cities (e.g. London, Montreal, and New York City), pledging that all new and existing buildings will have a low to zero carbon profile by 2030 and that all city-owned buildings will have a low to zero carbon profile by 2050.[6] To date, there have been no Marginal Abatement Cost Curves (MACC) developed to assess the net costs of such interventions.

The definition of a low to zero carbon building (also referred to a net-zero carbon building), according to the Green Building Council of South Africa (GBCSA)[7] is a highly energy-efficient building that is wholly powered from renewable energy sources that are on-site and/or off-site and may include off-sets that would neutralise a portion of the building operation's energy consumption. While embodied carbon is of significance as the sector represents at least 11% of global GHG emissions, embodied carbon is not considered under the definition of low to zero carbon buildings, which applies to the operational emissions from buildings.[7]

Energy efficiency makes up the foundation and largest component of a net-zero carbon building, where a net-zero carbon building refers to a building that emits very little to no GHGs and that is supported by supplementary renewable energy sources.[7] Reducing the energy demands within a building is priority before the addition of renewable energy systems or off-sets, so that the need for these systems, and the associated costs, is reduced to a minimum.[8] The building sector encompasses a diverse use of energy-intensive technologies that varies per sub-sector and building typology however, designing a building with energy efficiency in mind can significantly conserve the energy usage of a building in ways of allowing for natural sunlight thus reducing the need for lighting and where designing for appropriate ventilation reduces the need for space cooling.[8] Energy efficiency in buildings in this paper is strongly linked to net-zero carbon building, especially as energy supply is separated from buildings into different sectors as per the Greenhouse Gas Protocol (GPC).[9]

The eThekwini Municipality contributes 5% of the country's total GHG emissions, responsible for tCO_2e 29,025,638.[10] When accounting for emissions from electricity, the building sector represents 34% of eThekwini Municipality's GHG emissions and this is largely comprised of residential and commercial buildings.[11] With the eThekwini Municipality committing to a net-zero carbon building sector[6], this paper seeks to describe the cost implications associated with such a commitment. A MACC has been developed specifically for this study to present an analysis of the mitigation potential and associated costs for key sectors in the eThekwini Municipality for the years 2030, 2040, and 2050. The MACC provides insights into the net cost of an intervention that would abate or mitigate a tonne of carbon emissions. The MACC presents time-frames of 2030, 2040, 2050 across key sectors and highlights that the building sector offers significant GHG reductions at the lowest cost when compared to other high emitting sectors in the eThekwini Municipality.

2 Overview of the Mitigation Potential within the eThekwini Municipality

The development of a MACC requires an estimation of the GHG emissions that can be mitigated per intervention within a sector (abatement costs).[12] Typically countries and cities compile GHG emission inventories and use these as a basis to understand the opportunities to mitigate these emissions into the future.[12] This is commonly referred to as a Mitigation Potential Assessment, and essentially refers to the quantified potential to mitigate GHGs over specific timelines, and can also be referred to as the emissions-reduction potential.[13] Mitigation potential is calculated as the difference in GHGs from a baseline or business-as-usual future where emissions reductions occur based on current policy projections and from a future with enhanced emissions reductions.[5] Mitigation Potential Assessments model the interventions required to achieve the emissions reductions in the future and this provides a vital foundation on which the MACC is developed and calculated. This study builds upon existing research on the mitigation potential of high emitting sectors within the eThekwini Municipality conducted as part of the eThekwini Municipality's C40 Mitigation Pathways that was developed as part of a partnership between C40 Cities and the eThekwini Municipality to develop a Climate Action Plan (hereafter referred to as the 'CAP').[13]

The CAP published a mitigation potential analysis that modelled emissions growth scenarios for various sectors in the eThekwini Municipality until 2050 and these emissions projections are listed in Table 1. The CAP's emissions growth projections are built on the 2015 baseline of emissions provided by the eThekwini Municipality's GHG report[10] that uses guidelines for GHG reporting from the GPC[9]. The GPC's BASIC level of reporting that excludes the Agriculture, Forestry, & Other Land-use (AFLOU) and Industrial Processes and Product Use (IPPU) sectors.[9] Growth factors used within the CAP have been based on population and economic growth assumptions to inform future changes in the sectors analysed.[13] The CAP's mitigation potentials are displayed as sectors based on end-user allocations (aligned to the GPC[9]) of GHG emissions where a technical and market-based approach is applied to reducing emissions up to 2050.[13] A combined use of a technical and market-based approach means that emissions-reduction potentials are projected through tested interventions currently used around the world and to what portion of the market would readily adopt these interventions.[13,14] Aligned to this approach, South Africa published country-wide mitigation potential analyses that included a series of MACCs[14], and included a combination methodology of the two approaches to calculate the mitigation potential and its associated costs for sectors, aligned to the IPCC's 4th Assessment Report.[5]

However, a MACC did not accompany the mitigation potential analyses contained within the eThekwini Municipality's CAP and this paper seeks to fulfil that gap, focusing on the building sector. The MACCs calculated in this paper are for 10 year periods going up to 2030, 2040 and until 2050, using the CAP's modelled mitigation potential of sectors and their costs.

3 Development of a MACC for the eThekwini Municipality

3.1 Approach

Building on the work from the eThekwini Municipality's CAP Mitigation Potential assessment, the MACC produced in this study is the first of its kind for any Municipality in South Africa. The MACC of this study aligns to interventions used within the CAP[13] for only that are feasible from current technical and legal perspectives that is listed in Table 1 below. In determining the MACC, the interventions selected were aligned to the CAP[13] that used a combined technical and market-based approach that is based on the availability of each intervention and then modelled on the potential of the market that would adopt a GHG reducing intervention or technology.[14] Please refer to the supplementary material for more information on the limitations of the model with specific regards to the interventions.

Table 1: Technological interventions considered in the MACC for the eThekwini Municipality.

Sector/ sub-sector	**Technology intervention in the eThekwini Municipality's CAP**	**Considered in MACC**	**Reasons for non-inclusion**
Power			
Electricity generation	Power Grid Decarbonisation	No	Current legislated limitations to generating power
Electricity generation	Distributed Renewables	Yes	
Buildings			
New & Existing	Lighting	Yes	
New & Existing	Water Heating	Yes	
New & Existing	Insulation	Yes	
New & Existing	Heating & Cooling	Yes	
New & Existing	Equipment efficiency	No	Complexities of data collection
Industrial			
Industrial fuel switch	Fuel efficiency	No	Complexities of data collection
Industrial energy efficiency	Equipment efficiency	No	Complexities of data collection
Transport			
Road – mode shift	BRT – Bus Rapid Transport	Yes	
Road – fuel switch	Fuel efficiency	No	Complexities of implementation
Waste			
Landfill efficiency	Waste to Energy	Yes	
Increased recycling	Paper & Plastic Waste	Yes	
Increased composting	Food & Yard Waste	Yes	
Wastewater treatment method switch	Activated Sludge Treatment w/ Nitrogen Removal with Anaerobic Digesters	No	Intervention increases output of GHGs

3.2 Research Methodology

There is a set of core information that is necessary to generate a MACC for any area and these includes but is not limited to:

a) The calculation of the mitigation potential of sectors that would include the calculated volume of GHGs abated over a determined period.;
b) The full time frame of all interventions that would reduce GHGs within sectors;
c) The total lifetime costs of all intervention, that would include both capital and operational expenses;
d) Financial savings or returns resulting from interventions;
e) The cost of financing said interventions;
f) An uptake/ applicability factor;
g) Discount rates. [12,14]

The formula for calculating the net annual cost (NAC) is[13]:

NAC (R/year) = Equivalent Annual Cost (R/year) + Annual Operation & Maintenance Cost (R/year) – Energy Cost Saving (R/year)

The formula for calculating the marginal abatement cost is:

MAC (R/tCO2e) = Net Annual Cost (R/year) / Total Emissions Reduction (tCO2e/year)

The CAP has modelled and detailed distinct projects and interventions that reduce GHGs projected to 2050, for each of the assessed sectors and includes detail of the mitigation potential of each intervention up to 2050. For purposes of the MACC determined through this study, the costs were largely obtained from South Africa's national mitigation potential analyses[14] with additional local costings for the waste and transport sectors obtained from research done in eThekwini Area on the costs to provide a more localised and specific context.[15,16] An applicability rate was applied to each intervention already within the CAP, to effectively measure the rate of uptake that each sector would adopt for the intervention.[13] This was further based on the emissions profile of the sector, for example in the building sector, HVAC interventions were not considered for low-income houses and alternative methods of water heating were not considered for commercial warehouse buildings.[13] For purposes of the MACC developed in this paper, interventions were considered only where the data was adequately recorded by the eThekwini Municipality and that could be legally implemented at the time of publishing.

As there may be more than one intervention with differing lifetime periods, it is important to ensure that there is consistency in comparing lifetime costs, and this can be achieved by annualising the costs of each intervention.[14] This can be represented by utilising net annual costs that consider the capital costs, operational costs and any the associated costs minus the energy savings and / or revenue that may arise through the implementation of the intervention on an annual basis.[14] The costs are annualised to allow for comparison between other interventions, where the interventions may have differing life spans, and therefore differing net annual costs.[12]

As this study investigates the costs of mitigation potentials extending until 2050, a discount rate of 7% was applied and determines the present value of the money over 30 year time-frame.[14] A discount rate refers to the rate that will be used to discount a future value amount to its present value.[14] Electricity prices have been projected using South Africa's Integrated Resource Plan and is calculated for the building sector for avoided costs of electricity payments due to electricity usage reductions.[17]

The MACC for the municipality was developed in this study for the key sectors in the municipality for the years 2030, 2040, and 2050 taking into consideration the key interventions proposed in the CAP completed for the eThekwini Municipality. Table 2 provides a summary of the cost inputs used to determine the MACC in this paper, noting that all interventions, their scale, and their emissions reductions projection have been obtained from the CAP.

Table 2: Summary of input data costs per intervention, noting references to the sources of the input costs.

Summary of costs per intervention used to develop MACC								
Sector	Subsector	Interventions	Capital Cost	Operating Cost	Revenue generated	Avoided costs	Comments	Total emissions reduction (tCO_2e) per intervention (2030-2050)[12]
Energy	Power	Electricity: Distributed renewables (ZAR/ W)[18]	14.00	1.00	0.001830	-		1,718,182.13
Industry	Buildings	Residential: Lighting efficiency LED only (ZAR per building)[13]	1,825	-	-	561.25	1. Capital & operating costs averaged per building typology (e.g. new and existing, high income residential, low income) 2. Avoided costs from electricity reductions	534,213.33
Industry	Buildings	Residential: Building insulation (ZAR per building)[13]	1,000	-	-	142.58	1. Capital & operating costs averaged per building typology (e.g. new and existing, high income residential, low income) 2. Avoided costs from electricity reductions	819,862.95
Industry	Buildings	Residential: Efficient Water Heating (ZAR per building)[13]	800.00	26.00	-	196.07	1. Capital & operating costs averaged per building typology (e.g. new and existing, high income residential, low income) 2. Avoided costs from electricity reductions	318,259.37
Industry	Buildings	Commercial: Lighting efficiency LED only (ZAR per m^2)[13]	2.83	-	-	19.36	1. Capital & operating costs averaged per building typology (e.g. new and existing, warehouse, office) 2. Avoided costs from electricity reductions	1,750,842.49
Industry	Buildings	Commercial: Efficient Water Heating (ZAR per m^2)[13]	37.30	0.90	-	0.99	1. Capital & operating costs averaged per building typology (e.g. new and existing, warehouse, office) 2. Avoided costs from electricity reductions	109,956.71
Industry	Buildings	Commercial: HVAC with Heat Recovery (ZAR per m^2)[13]	14.60	1.20	-	2.98	1. Capital & operating costs averaged per building typology (e.g. new and existing, warehouse, office) 2. Avoided costs from electricity reductions	162,629.45
Transport	Road	Mode Shift: Bus Rapid Transit (ZAR '000 per KM)[16]	1,779.95	46.32	109.23	-		7,917,652.68
Waste	Municipal Solid Waste	Landfil Gas to Electricity (ZAR per m^3)[15]	16,222.22	9,333.33	527.86	-		506,940.00
Waste	Municipal Solid Waste	Food and yard composting (ZAR per tonne)[15]	3,204.69		33.65	154.79	1. Revenue generated through sale of recycled product 2. Avoided costs of landfilling	474,344.20
Waste	Municipal Solid Waste	Paper recycling (ZAR per tonne)[13]	381.36	358.35	198.53	154.79	1. Revenue generated through sale of recycled product 2. Avoided costs of landfilling	713,860.00

4 Marginal Abatement Cost Curves for the eThekwini Municipality

4.1 The Building Sector

The interventions represented by the MACC show a generalised emissions reduction cost for all building typologies in the residential and commercial sectors. This includes a projected amount of newly constructed buildings that would be built with energy efficient interventions and on the number of existing buildings that would be converted to energy efficient buildings.

For the first period in analysis (2030-2040), the building sector is the only sector that provides a return on investment. This is displayed on the graph as a negative cost (Figure 1). To aid in reading the MACC, it is important to note that the width of the graph on the horizontal axis specifies the amount of potential carbon emissions abatement (tCO_2e) whereas the vertical axis displays the modelled costs for the reduction in carbon emissions specific to the intervention used (ZAR/tCO_2e).

With six interventions arising from the building sector, three of these interventions result in a negative financial implication, which means that these interventions result in energy savings that surpass the capital and operational costs within the first 10 years. The shift from Compact Fluorescent Lights to LEDs offers the most emissions reductions potential for the residential and commercial sectors and is inclusive of existing and new buildings to provide a negative cost. Implementing efficient HVAC technologies in new commercial buildings also provides a negative cost and contributes towards emissions reductions. The 2030 MACC for the building sector (Figure 1) does show interventions that incur a cost, namely solar water heating interventions and insulation measures.

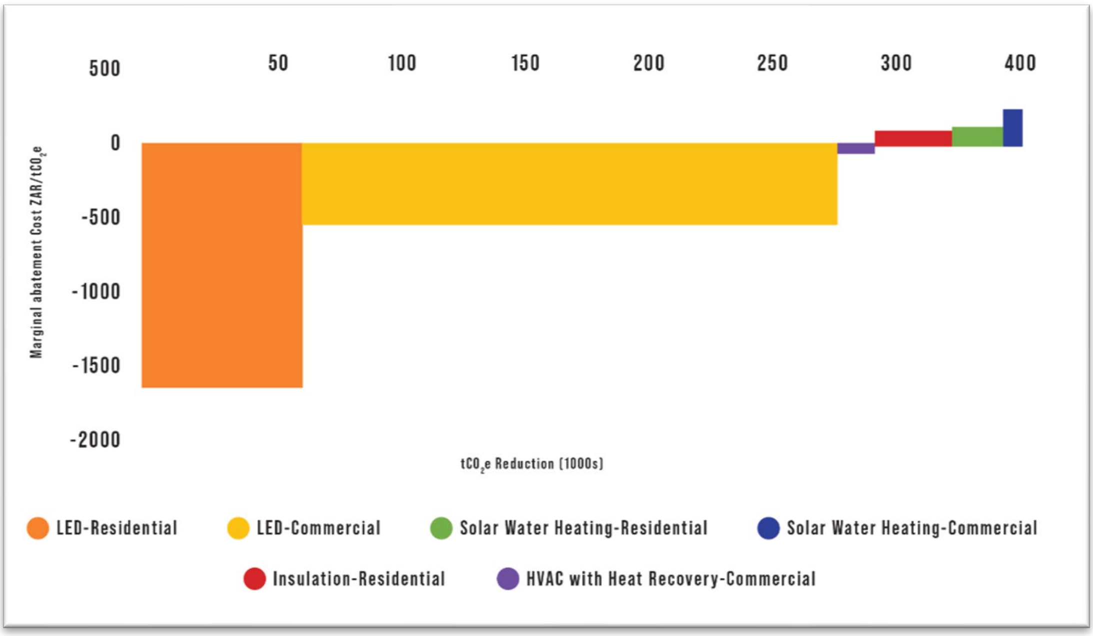

Figure 10: MACC for building sector in 2030.

Lighting interventions within commercial buildings consistently deliver the most GHG reductions in each time frame while the residential lighting interventions offers the most cost-effective solution. Interventions to increase the insulation of residential buildings are slowly applied at a rate of 5% in 2030 and cumulatively increasing to 10% for 2040, and steeply increasing to 80% of all residential houses by 2050 which account for the significant growth in GHG reductions from this intervention.[13]

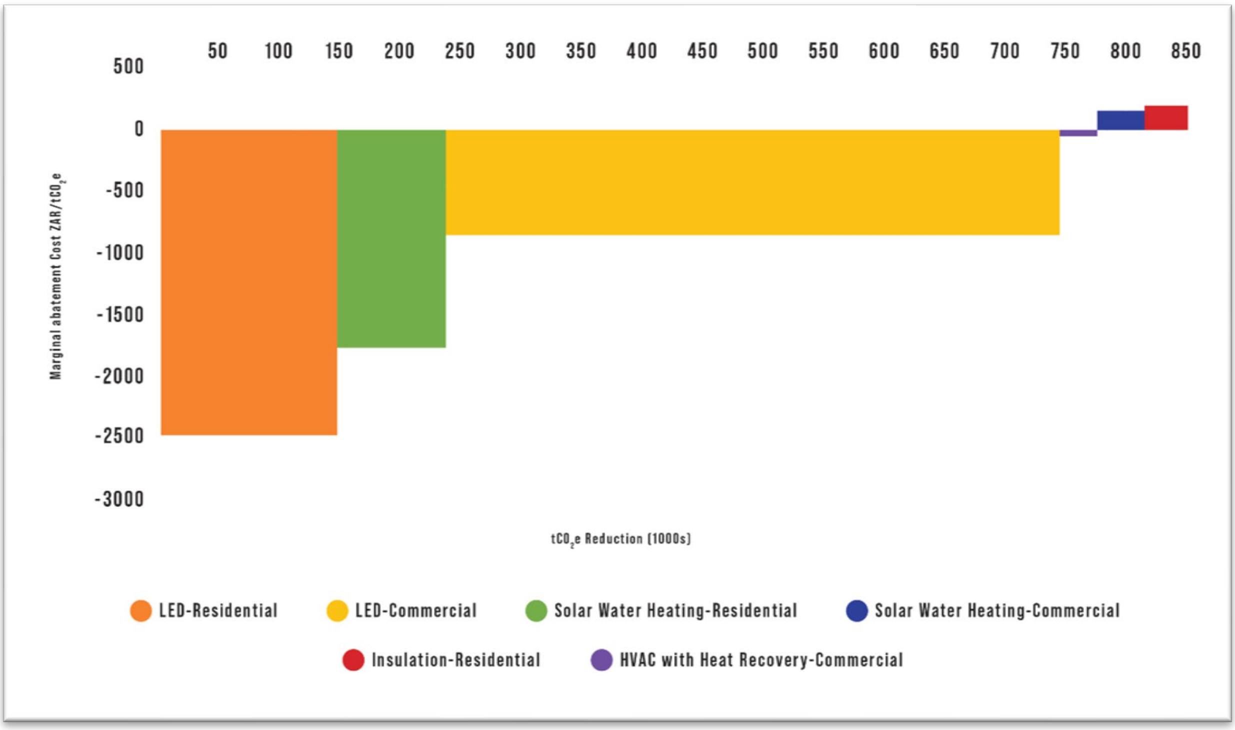

Figure 11: MACC for building sector in 2040.

Figure 2 displays the MACC for the building sector for the period of 2030 – 2040. Solar Water Heating for the Residential market now results in a negative cost in addition to lighting interventions, the commercial sector's solar water heating, and the residential sector's enhancement of insulation interventions.

In 2050, Figure 3 displays a full range of interventions within the building sector that all result in a negative cost. This means that there is not a single intervention in the building sector that does not provide a return on investment within the 10-year period from 2040 to 2050. The graph for GHG reducing interventions for the Commercial sector for *HVAC with Heat Recovery* does not display in the scale of the graph as results show a slight negative cost of ZAR20 per kiloton of carbon emissions reduced.

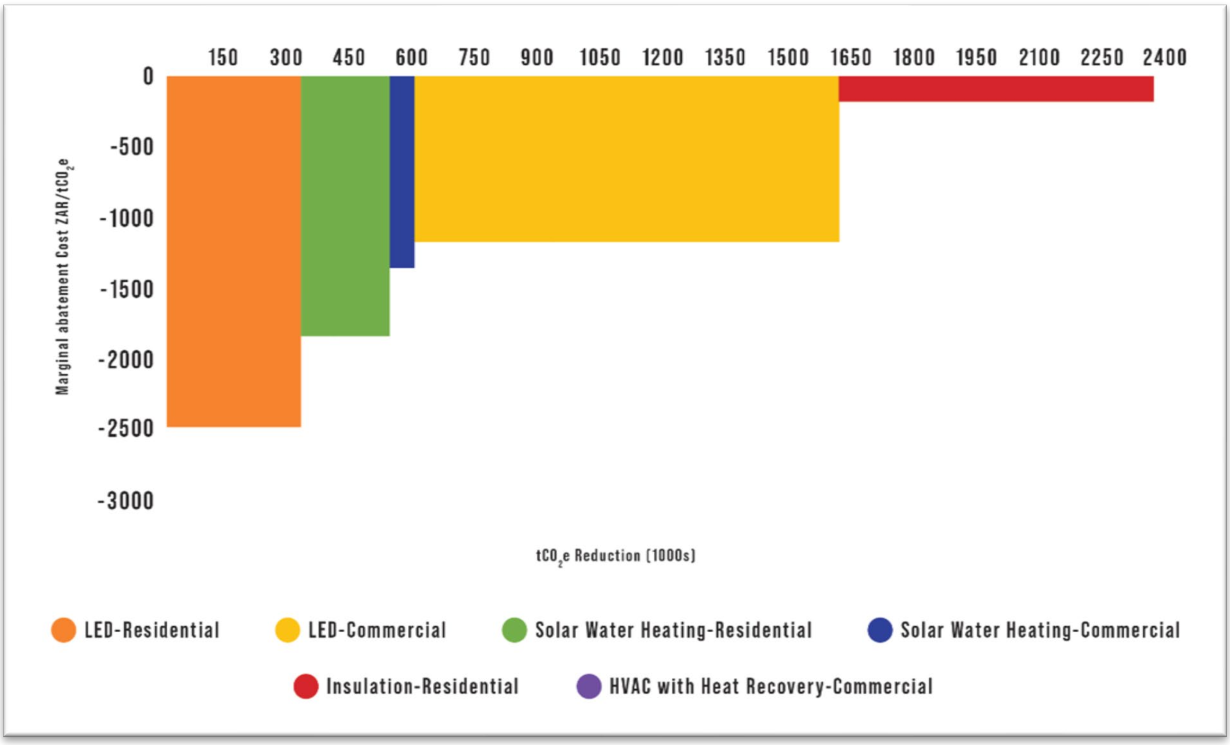

Figure 12: MACC for building sector in 2050.

4.2 MACC for Stationary energy - implementing distributed renewable energy generation

Distributed generation refers to electricity that is being produced by multiple grid-connected generation systems generally from residential and commercial buildings.[17] In this manner, energy is generated closer to where it will be consumed in comparison to conventional energy supply systems in South Africa and is commonly referred to as small-scale embedded generation.[18] Distributed generation of electricity is thus characterised by a decentralised supply, where electricity is consumed closer to where it is generated. For small-scale distributed generation, generation is derived from buildings, and in the context of the eThekwini Municipality it should be done via rooftop photovoltaic panels. The Integrated Resource Plan (IRP) sets out that small-scale embedded generation use is restricted to a single customer, and this implies boundaries around distributing energy.[17]

In this study, the costs of integrating distributed renewable energy by means of small-scale embedded energy generation (SSEG) that is legally allowed were calculated. The costs were calculated through utilising current market costs per Watt to install SSEG in the eThekwini Municipality.[18]

Figure 4 graphically displays the MACC for the distributed generation of renewable energy for all periods of 2030, 2040, and 2050. The Y-axis represents the cost of reducing a single ton of carbon dioxide, where there is a cost implication of R13,982.30 to reduce one kilotonne of carbon emissions for the year 2030, and similar costs of R17,461.65 and R20,492.90 to reduce a kilotonne of emissions for 2040 and 2050 respectively.

While costs for distributed generation increases in the second decade of implementation, there is a strong reduction in emissions that increases about 300% and further rises to over 500% in 2050.

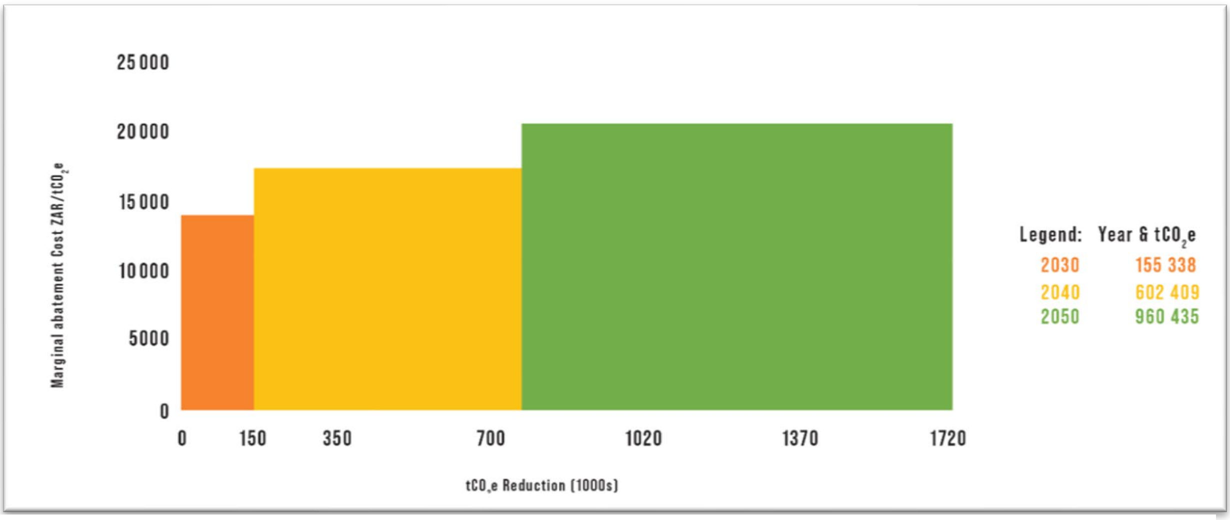

Figure 13: MACC for distributed renewable energy supply in 2030, 2040, and 2050.

4.3 MACC for implementing low carbon transportation

For low-carbon transportation, this MACC focuses on Bus Rapid Transit (BRT) systems that refers to a road-based solution to providing public transportation services that are accessible and more affordable than rail systems.[13] This intervention involves increasing the modal share of the usage of buses as opposed to passenger automobiles in the Municipality.[16] Despite the name of this intervention, the eThekwini Municipality follows the approach of a dedicated lane for a high occupancy transport vehicle using standard city buses that is not of the usual BRT design.[16] This is different from the City of Johannesburg, the City of Tshwane, and the City of Cape Town that operates buses designed to be specific to the needs of the BRT system.[16] This means that the capital costs arising for the Municipality largely focuses on the infrastructure costs of implementing a BRT system.

Due to the sector containing a single intervention only, the full period from 2030 to 2050 is displayed on a single graph in Figure 15. Evidently, the cost implication of this intervention reaches over R35000 to reduce a single kiloton of carbon emissions in 2030 but drops sharply to 2040 by 79% and with the emissions reduction potential increasing substantially by 490% (Figure 5).

Despite the high costs, providing safe and accessible public transportation systems is already a priority in the Municipality and will provide far-reaching social and economic benefits that have not been quantified in this study.

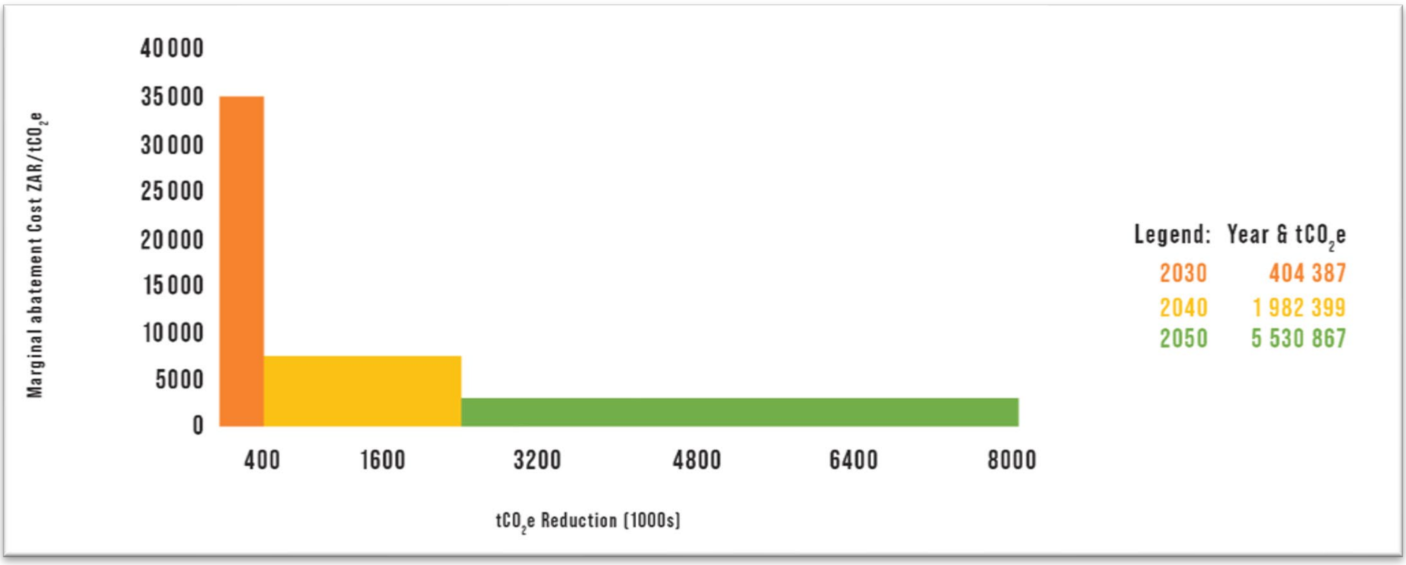

Figure 14: MACC for transportation sector in 2030, 2040, and 2050.

4.4 MACC for the Waste sector

This sector includes interventions for the recycling of paper and plastic, composting of food and garden waste, and capturing landfill gas for electricity. These interventions incur costs to reduce carbon emissions with no direct payback economically. However, the reduction and recycling of waste materials will have significant environmental and social benefits beyond reducing carbon emissions such as conserving landfill space and reducing the leachate of pollutants from landfills.

The MACC for the recycling of waste takes into account the capital costs of setting up the collection, sorting, and recycling services specific to the waste type and the operating and ancillary costs of these services and finally considering the revenue generated from the sale of the recyclable or recycled material that would have ordinarily been discarded.[14] The costs for composting of food and yard waste refer to home composting methods where it is assumed that 50% of urban households have gardens and that the uptake rates for home composting by households in the eThekwini Municipality is 50% for food waste and 75% for garden waste, and this uptake rate remains consistent across the assessed period (2030-2050).[13] The costs for home composting involve the purchasing on composting bins and the value of compost produced, combined with the reduced costs of waste going to landfill.[14] The costs and income figures for both the recycling and composting interventions were obtained from the national report for South Africa's MACC.[14]

The eThekwini Municipality has a noteworthy case study of converting landfill gas to electricity at the Bisasar Road landfill, and costs from this existing measure were analysed and extrapolated to present a cost estimate for increasing and maintaining this intervention in 2030, 2040, and 2050.[15] The revenue generated from this intervention is derived from the sale of electricity produced from the captured gas, and is scaled upwards based on the IRP's electricity cost projections.[17]

As displayed in Figure 6, the recycling of paper to reduce GHG emissions arising from the waste sector by 2030 provides the lowest abatement cost per kiltonne of carbon emissions reduced while converting landfill gas to electricity provides the highest carbon emissions reduction for 2030 in this sector. It can be noted in Figures 6, 7, and 8 that the costs of landfill gas extraction largely remain the same while the emissions reduction potential decreases over time. The eThekwini Municipality has been implementing landfill gas intervention programmes since the early 1990s for purposes of minimising negative health and safety impacts.[15] The municipality in 2000 pioneered the first registered Clean Development Mechanism (CDM) project in Africa through their landfill gas to electricity intervention.[15] Due to the sub-tropical climate of the eThekwini Municipality, the majority of available landfill gas is extracted earlier in the life of a landfill with a high methane content.[15]

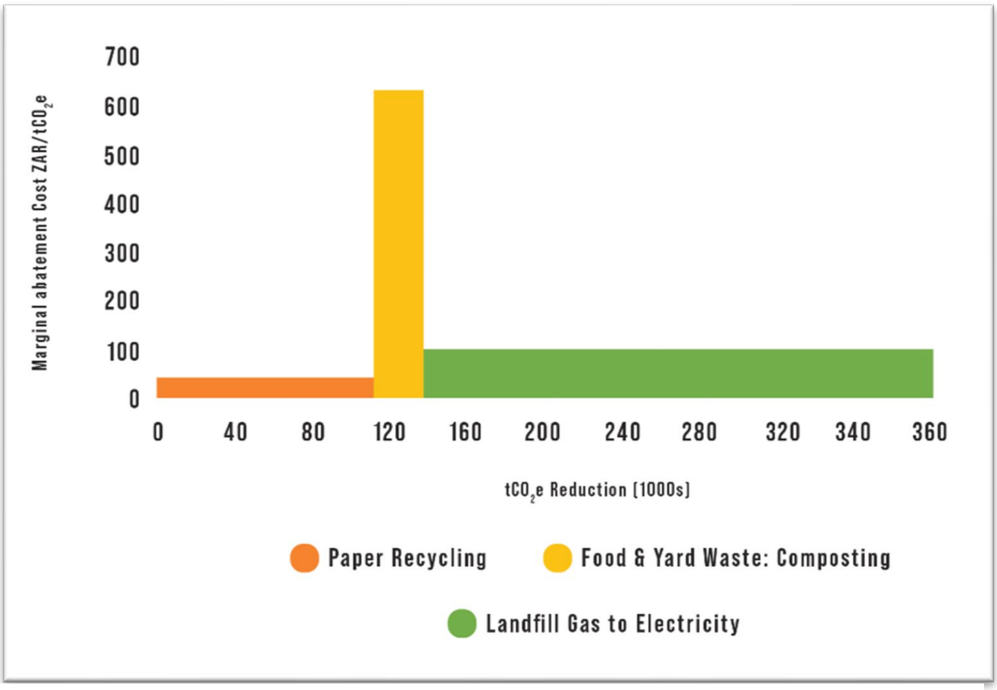

Figure 15: MACC for waste sector in 2030.

It is interesting to note the low costs arising from the recycling of paper. Outside of the Building Sector, paper recycling has the lowest abatement cost and offers a consistently low cost until the end of the period in this study. The case for emissions reductions with paper recycling improves as Figure 7 shows that emissions reductions increased 216%. The total increase in emissions reductions for the entirety of the assessed period until 2050 is 346%, and this can be viewed through an increase from Figure 6 through to Figure 8, where Figure 8 is the final period of assessment. While the costs for paper recycling largely remain the same, there is a compelling case to be made through the significant reduction of GHGs.

The composting of food and yard waste is a contrasting image in this sector as the costs and emissions reductions remain consistent throughout the assessed periods. These costs are the highest of all assessed interventions, and the emissions reductions potential is notably the lowest. It is important to note that the scale of intervention applied to the sector is also consistent for all three periods, being implemented in three parts across the assessed periods between 2030 to 2050.[13]

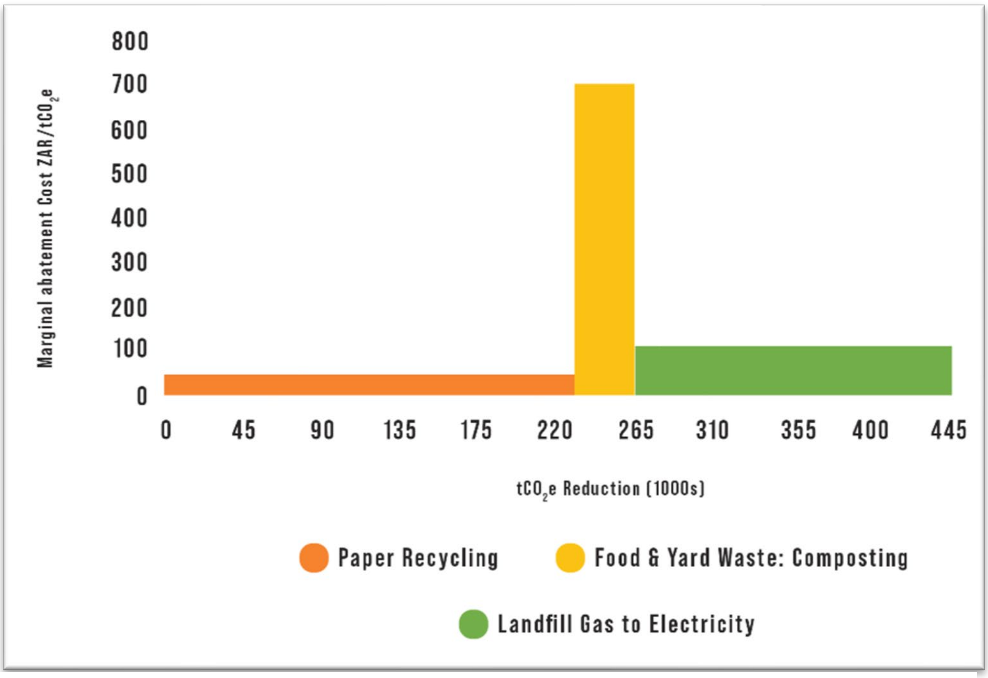

Figure 16: MACC for waste sector in 2040.

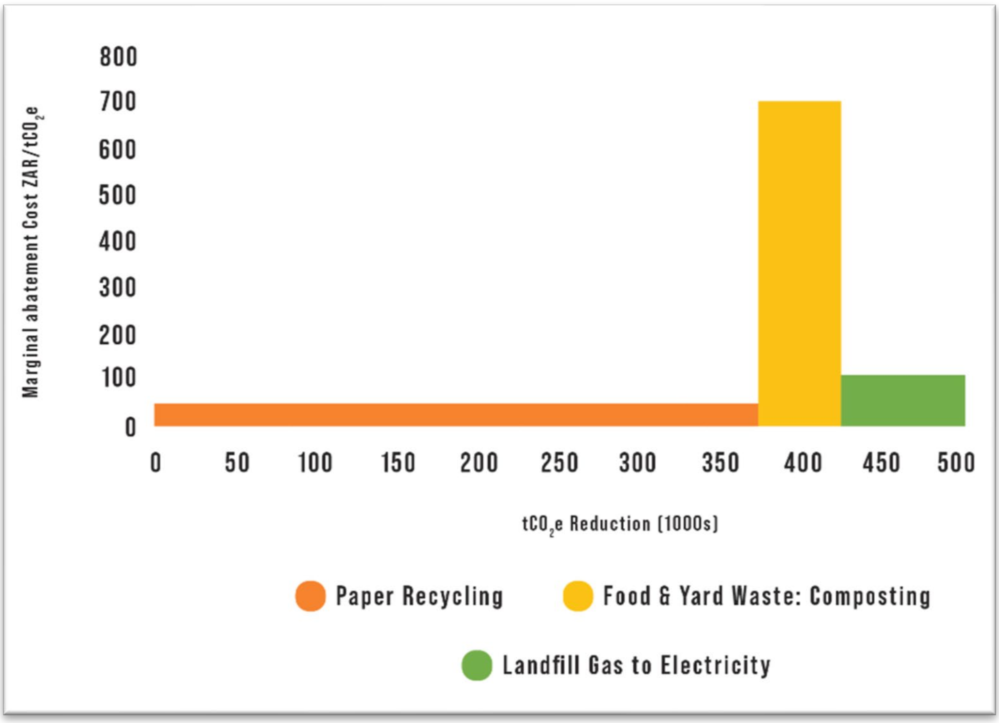

Figure 17: MACC for waste sector in 2050.

5 Summary of Results

The IPCC[5] demonstrated that on a global scale the building sector could contribute towards achieving the goals outlined by science in the Paris Agreement.[5,6] South Africa's national MACC calculated in 2016 highlighted the building sector to offer the most emissions reductions at the lowest cost when compared to all other sectors.[14] This study confirms that the building sector in the eThekwini Municipality offers the highest abatement potential at the lowest cost when compared to any other sector, aligning to previous studies by C40, ICLEI.[3,6]

The determination of the eThekwini Municipality's GHG mitigation potential conducted for the CAP provided a key departure point for the development of the MACC for emissions reductions forecasts within the municipality. Based on the MACC, the buildings sector offers the lowest cost to reduce GHG emissions when compared to the other studied sectors. Several interventions within the building sector display negative costs, indicating that the intervention will have a positive payback period throughout its lifecycle. The building sector, out of all analysed economic sectors in the eThekwini Municipality, dominates the first percentile of abatement costs that refers to the lowest cost interventions (please refer to the supplementary material for more information on the percentiles). This indicates that the building sector should be prioritised for early actions as it represents the most cost-effective sector to reducing the first 25% of the eThekwini Municipality's available lifetime mitigation potential. All interventions to reduce GHG emissions up to 2050, in the building sector provides a return on investment. The intervention with the lowest costs is the installation of efficient LED lighting in both new and existing buildings for both the national MACC[14] and for the MACC developed for the eThekwini Municipality in this paper.

The waste sector has the second lowest abatement costs in the eThekwini Municipality. The transportation sector displays the highest abatement power across all assessed sectors for the eThekwini Municipality, and this is followed by the power sector. The low costs for the waste sector largely arises from the revenue generated through the resale of the waste material and also for reducing the costs associated with landfilling, where there are costs to landfill in the eThekwini Municipality and in South Africa. The waste sector represents the sector with the third lowest cost for the national MACC but this is due to the consideration of the AFLOU sector in the national MACC that was not accounted for in the CAP.[13,14] It is important to note that a MACC is not meant to be the final deciding factor for policy makers, but that it does add to an important basket of factors that need to be considered when planning for future climates in cities.

The building sector represents a unique opportunity for the eThekwini Municipality to serve as best practice by taking appropriate climate action, and in optimising service delivery offerings to inhabitants at lower operating and administrative costs.

6 Summary and recommendations

The determination of the eThekwini Municipality's GHG mitigation potential conducted for the CAP provided a key departure point for the development of the MACC for emissions reductions forecasts within the municipality. Based on the MACC, the building sector offers the lowest cost to reduce GHG emissions when compared to the other studied sectors. Interventions to reduce GHG emissions in the building sector fall into the first percentile that refers to the lowest cost interventions (refer to supplementary material) meaning that there is significant potential for mitigation of GHGs within the building sector. As the Municipality has publicly committed to ensuring that that all new and all municipal-owned buildings will have a net-zero carbon profile by 2030 and that all existing buildings will have a net-zero carbon profile by 2050, the potential is that about a third of GHG emissions in the Municipality could be mitigated.

The MACC developed in this study confirm that the building sector will deliver the highest amount of GHG reductions at the lowest amount of costs in the eThekwini Municipality, however only through energy efficiency measures. It is therefore recommended that the building sector be prioritised in the list of actions needed to address climate change. Not only is the building sector a low-cost and high potential sector, but also serves as a scaled approach to address a wide variety of sustainability issues such as water conservation and waste management. Ensuring resource efficiency in the building sector will f add to the continuity of operations within buildings, minimising disruptions and ensuring that the Municipality has an attractive space for investment and living.

Due to the magnitude of such a complex assessment, the scope of assessing the economic potential in this study was focussed on the financial bottom-line costs of the interventions which is limited to the capital and operation costs, with no consideration given to social costs and benefits and social discount rates. It would be invaluable to consider the social costs and benefits such as job creation, and the quantification of the costs of future threats to the eThekwini Municipality. It is important to note that the MACC does have limitations as it neglects to account for societal changes and behavioural studies, and does not account for a holistic representation of all externalities that may have negative local economic impacts such as local air pollution.[17] Furthermore, the MACC does not account for potential benefits that will arise through mitigating climate change and from the reduction of future risks.

It is recommended that future studies explore all sectors aligned to the BASIC + system of reporting and that outcomes assessed further include in data that goes beyond the scope of this research that would describe the number of jobs created per intervention, the economic implications on GDP arising from the implementation of the intervention, and the associated social benefits.

Furthermore, while this study broadly highlights the building sector as offering significant GHG emissions reductions at the lowest abatement cost, a more detailed study that includes interventions within the industrial sub-sector is recommended. Industrial efficiency interventions offer a larger amount of mitigation potential than the building sector, almost three times as much, though currently accessing such data from industries has proven difficult and requires greater partnerships to unlock these barriers.

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Supplementary Material

S1. Methodology for development of a MACC for the eThekwini Municipality

The MACC established in this study takes the assessed mitigation potential analyses from the eThekwini Municipality's Climate Action Plan (CAP) report and further quantifies the cost of reducing GHGs per intervention.[1]

Mitigation potential assessments require extensive analyses of baseline inventories to model a series of future emissions trajectories based on current emission reduction trends (baseline case) and on enhanced emission reduction futures, where the projections are based on estimated population and economic growth.[2] The data inputs require establishing the detail within scenarios that would describe the GHG reducing interventions, and its projected applicability and market uptake of intervention within its sector.[1,2] As part of the CAP[1] assessment, a detailed model was produced that described emissions growth scenarios within various sectors up until 2050. The CAP's emissions growth projections are built on the 2015 baseline of emissions provided by the eThekwini Municipality's GHG accounting report[3] that uses guidelines for GHG reporting from the Greenhouse Gas Protocol (GPC)[4]. Growth factors used in the CAP[1] were based on population and economic growth assumptions to inform future changes in the sectors analysed. Gross Domestic Product (GDP) per capita is used as an indicator for economic growth, and while it is acknowledged that this measure should not be solely used to make conclusions about the state of a nation, it is a relatively simple indication of real and inflation adjusted growth for sectors within an economy.[1]

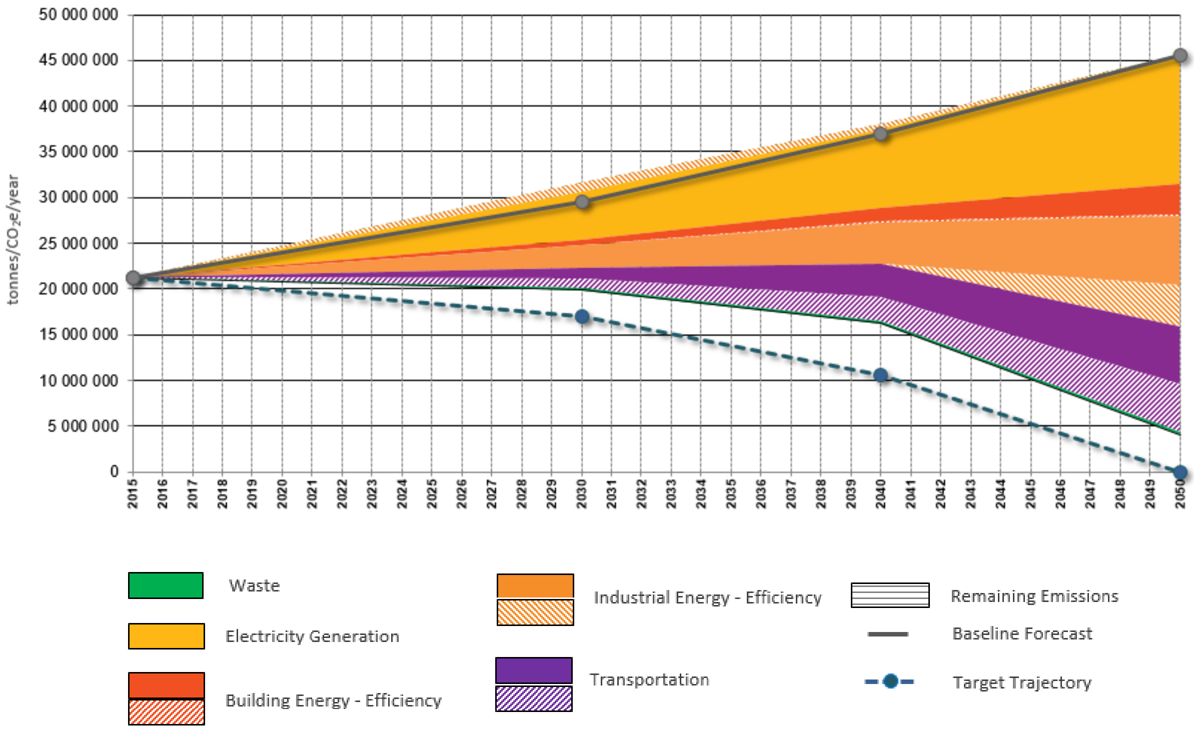

Figure 1: Emissions reduction potential within the eThekwini Municipality 2015 – 2050[1]

Figure 1 presents the emissions reduction potential within sectors in the Municipality. Displayed by the topmost line, the upper end of the trajectory illustrates emissions increase without any further mitigating interventions being implemented while the lower end of the trajectories show the emissions projections where maximum mitigation efforts have been implemented.[1] The difference between the upper and lower scales on the graph indicate the ranges for mitigation potential for each sector.

Mitigation potential of sectors can be modelled through individual or a combination of a Technical Potential Approach that explores the potential reductions in GHG emissions through interventions based on existing and available technologies, an Economic Potential Approach that accounts for potential GHG reductions and the associated costs through a cost benefit analyses, and a Market Potential Approach whereby the potential of the market that would adopt a GHG reducing intervention or technology is analysed.[2]

This study builds on the eThekwini Municipality's CAP report and applies a financial consideration to the reduction of GHGs by producing a MACC.[4] The sectors covered in this assessment of a MACC aligns with the approach used within the CAP that employs a technical and market-based approach. It is common to utilise a combination of approaches to determine mitigation potentials and MACCs. In the CAP, a market potential approach was used for the certain building typologies where as an example, HVAC interventions were not considered for low-income houses and alternative methods of water heating were not considered for commercial warehouse buildings.[2] A technical potential approach used for the remaining building typologies.[2]

In 2016, South Africa published country-wide mitigation potential analyses that included a series of MACCs,[2] that modelled the GHG emissions reduction potential of each sector, the associated net costs and social benefits in this analysis and included a combination methodology of the technical and market potential approaches to calculate the mitigation potential and its associated costs for sectors, as did the IPCC's 4th Assessment Report.[5] From the modelled results of the CAP[1], is must be noted that the Municipality falls short of reaching zero-emissions by 2050.

This provides impetus for the Municipality to fast track climate action and to prioritise low-cost interventions in reducing GHG emissions, as cost increasingly becomes an issue in addressing climate change.

As there may be more than one intervention with differing lifetime periods, consistency in comparing lifetime costs is important and can be achieved by annualising the costs of each intervention.[6] Net annual costs that consider the capital costs, operational costs, and any the associated costs minus the energy savings and/or revenue that may arise through the implementation of the intervention on an annual basis can be utilised.[2,6] The costs are annualised to allow for comparison between other interventions, where the interventions may have different life spans, and therefore differing net annual costs.[2]

The input data used for this study was derived from a range of sources, including the local market and national market rates. National market rates for technical interventions were obtained from South Africa's national mitigation potential analyses[2] with local costings for the waste and transport sectors obtained from existing research to provide a more localised and specific context.[7,8]

S2. Limitations of model

S2.1 Power: Grid Decarbonisation

In spite accounting for a significant portion of the mitigation potential identified within this sector of the CAP Mitigation Analyses, this measure is excluded from this marginal abatement cost study due to current legislated limitations to generating power.

Local Authorities in South Africa are limited to the amount that power that they can generate independent from Eskom, the national utility. Electricity is currently generated solely by parastatal Eskom with a small but increasing share of Independent Power Producers adding to South Africa's electricity supply. South Africa's draft Integrated Resource Plan (IRP), which is a plan of the country's future electricity capacity, apportions 200MW annually for embedded generation that is limited to between 1MW to 10MW for a single customer.[9]
It is however apparent that a long-term solution would mean that cities should become generators as businesses and residences move off the grid and in turn reduce revenues from electricity sales within the city.

Further to this, there are inherent complexities in calculating net annual costs for the integration of large amounts of varied decentralised renewable power into the existing grid. To calculate the capital costs would require conducting a study on the applicability of the types of renewable energy sources that should be used - where the location of these power sources would substantially influence their input costs. The eThekwini Municipality has begun the process by producing a set of research for long term diversification and sustainability of energy supply contained within the Energy Strategic Road Map.[10] Similarly, the determination of the operating costs would also vary per energy source.[10] Significant importance should be consideration to the tariffs and energy charges that the Municipality will need to consider to ensure feasibility of these additions to the grid, which is included in the net annual costs as the returns or savings amount of the intervention. It is recommended that municipalities determine their energy futures strategically, to ensure a more stable and a cleaner energy grid.

S2.2 Industry: Industrial efficiency and Industrial Fuel Switch

Following the GPC's BASIC method of reporting, this study did not include industry and AFLOU sectors. A large aspect of this omission is due to the lack of data from the eThekwini Municipality, however, these figures were estimated and modelled into the CAP.[3,1] The lack of data stems from the complexities in collecting data from a broad range of differing industrial companies. The data is vital to understand the GHG emissions contribution from the industrial sector and resulting reductions and also of detailing the costs involved to reduce GHGs.[2] Within the Industry sector, mitigation potential analyses would include industrial equipment efficiency and fuel efficiency shifts for industrial facilities located within the eThekwini Municipality.[1] Evaluating this sector would require a meaningful understanding of industries' processes and equipment used in order to best evaluate their technical potential mitigation.

S2.3 Waste: Treatment of Wastewater

The treatment of wastewater is omitted from this study due to the CAP mitigation potential study including the anaerobic digestion of wastewater without biogas capturing as a necessary environmental intervention which however then results in an increase in the amount of GHG emissions released, compared to conventional aerobic wastewater treatment processes. The treatment and disposal of sewage sludge are part of key design aspects for wastewater treatment plants because of the high costs associated with treating and safely disposing of this waste in accordance to legislation.[11] Anaerobic wastewater treatment processes significantly reduce the volume of sludge produced, which then reduces the amount of treatment required to handle the sludge without being a health hazard.[11] Since there is no mitigation potential for GHGs relating to wastewater treatment[1], this measure was not assessed for its marginal abatement cost to reduce GHGs, however it is important to note that anaerobic digestion processes for wastewater treatment has many environmental benefits, and the increased output of GHGs can be mitigated through interventions such as gas to electricity, and also in creating useful products such as fertilisers.[11]

S3. Percentile Results

A MACC is intended to be used as part of an array of evidence that would inform effective investment into long-term and workable climate change mitigation programmes. A MACC provides insights into the net cost of an intervention that would mitigate a tonne of carbon emissions.[2]

Varying percentiles of marginal abatement cost per sectors analysed for 2050 are presented in Figure 1. The use of percentiles has several advantages that include highlighting the values that fall within the most cost-effective bracket of below 25% and noting the interventions that increase in costs through its categorisation in the following percentiles. Interventions falling under the 25% category refers to the 'easy-wins' or low-cost interventions going up to the year 2050.

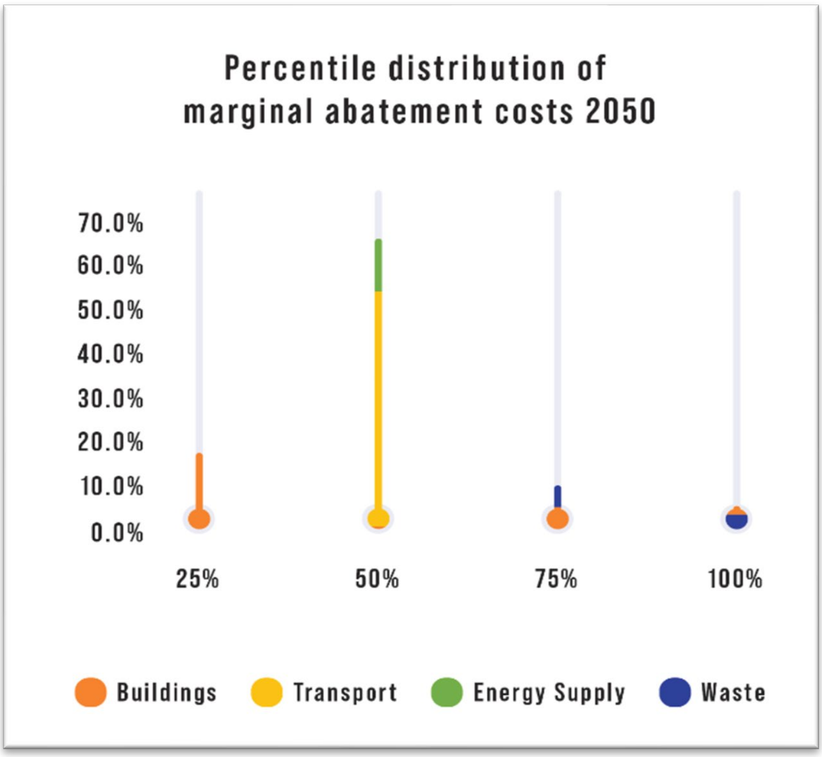

Figure 18: 2050 split of marginal abatement costs displaying percentile distribution and percentage of mitigation potential of analysed intervention.

Table 1 presents the results from the CAP Mitigation Potential Analyses[4] with the MACC findings arising from research conducted in this paper and includes sectors that have been omitted from the marginal cost abatement calculations. The table further details the interventions used within mitigating GHGs in sectors and the percentage of emissions reductions for 2030, 2040, and 2050.

The building sector to offer significant GHG emissions reductions at the lowest marginal abatement cost. The building sector can be described as one that is integral to people's safety and living. Buildings are immovable and fixed assets – unlike the energy behaviours and demands of its occupants. Buildings as structures last for well beyond a hundred years, and therefore constructing these buildings to be net-zero carbon from the on-set will ensure that the building stock of the future is low carbon.

Table 1: Total interventions used within mitigating GHGs in sectors and the percentage of emissions reductions for 2030, 2040, and 2050.

Summary of city-wide emissions reduction potential and marginal abatement costs			2030		2040		2050	
Sector	Subsector	Interventions	% of total emissions reduction	Marginal Abatement Cost (ZAR/ $KtCO_2e$)	% of total emissions reduction	Marginal Abatement Cost (ZAR/ $KtCO_2e$)	% of total emissions reduction	Marginal Abatement Cost (ZAR/ $KtCO_2e$)
Energy	Power	Electricity: Distributed renewables	1,6%	13,98	2,9%	17,46	2,45%	20,49
Energy	Power	Grid decarbonisation	51,7%	Not calculated	38,9%	Not calculated	31,70%	Not calculated
Industry	Buildings	Residential: Lighting efficiency LED only	<1%	-1,60	<1%	-2,45	<1%	-2,48
Industry	Buildings	Residential: Building insulation: new and redeveloped	1,4%	0,09	1,2%	0,18	1,97%	-0,17
Industry	Buildings	Residential: Efficient Water Heating	<1%	0,12	<1%	-1,76	<1%	-1,84
Industry	Buildings	Commercial: Lighting efficiency LED only	2,4%	-0,52	2,4%	-0,83	2,46%	-1,15
Industry	Buildings	Commercial: Efficient Water Heating	<1%	0,25	<1%	0,15	<1%	-1,34
Industry	Buildings	Commercial: Efficient HVAC (new build)	<1%	-0,04	<1%	-0,01	1,1%	-0,01
Industry	Buildings	Commercial: Efficient HVAC (existing build)	1,1%	1,07	1,7%	5,76	1,8%	-2,12
Industry	Buildings	Other: Equipment Efficiency, space heating, cooking	2,1%	Not calculated	2,3%	Not calculated	2,51%	Not calculated
Industry	Industrial	Industrial equipment efficiency	25,1%	Not calculated	22,1%	Not calculated	18,20%	Not calculated
Industry	Industrial	Industrial fuel switch	-11,0%	Not calculated	-2,5%	Not calculated	10,70%	Not calculated
Transport	Road	Mode Shift: Bus Rapid Transit	4,1%	35,06	9,5%	7,65	13,30%	3,04
Transport	Road	Fuel efficiency: Passenger and transit vehicles	19,0%	Not calculated	20,4%	Not calculated	14,00%	Not calculated
Waste	Wastewater	Shift to anaerobic digestion	-1,1%	Not calculated	<-1%	Not calculated	<-1%	Not calculated
Waste	Municipal Solid Waste	Landfil Gas to Electricity	2,6%	0,10	<1%	0,11	<1%	0,11
Waste	Municipal Solid Waste	Food and garden composting	<1%	0,62	<1%	0,67	<1%	0,68
Waste	Municipal Solid Waste	Paper recycling	1,0%	0,04	1,1%	0,05	<1%	0,05

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Chapter 4: Towards a low carbon emissions legacy in the building sector, the case study of Durban

Abstract

As the building sector is established to be the sector that provides the least economic challenges to GHG reductions, the question remains on whether the focus should be placed on new or existing buildings. The feasibility of implementing mandatory net-zero carbon principles for new buildings where the focus is on energy efficiency was investigated in this paper. There are many aspects that influence feasibility, and this research uses a basic economic approach for evaluating feasibility while describing some literature around other aspects of feasibility with regards to new and existing buildings, using the eThekwini Municipality (Durban) as a case study. The results are displayed through the use of an input-output model specifically developed for this study, entitled the "Net-Zero Carbon Energy Efficiency Cost Model". This model explores sub-sectors within the building sector to narrow down the selection of climate change mitigation projects within the building sector. The cost model accounts for differences in lifecycle costs for new buildings to be constructed with enhanced energy efficiency, for existing buildings to be retrofitted with enhanced energy efficiency, and for buildings with standard energy efficiency requirements contained within existing building regulations. Energy efficiency results in cost savings from reduced energy costs and thus it is important to establish the full life cycle costs between energy-efficient buildings when compared to standard buildings. The initial costs is currently higher to develop energy-efficient buildings and this study aims to determine the costs over a full life cycle. The calculator looks at these building typologies over a 30 year period, and these findings will serve as a tool to assist decision-makers in prioritising climate actions that will provide a high abatement potential at the least costs.

Most buildings already in existence in the municipality were not designed with energy efficiency principles in mind and that most of the existing building stock was not constructed before the National Building Regulations implemented mandatory requirements for energy efficiency in buildings in 2011. Existing buildings types offer a strong business case for retrofitting energy efficiency; such as low-rise office blocks, shopping malls, and school blocks. These building types show a payback period of fewer than two years for retrofitted energy efficiency which is a viable payback period similar to that of new buildings. However, ensuring that existing buildings retrospectively comply with current regulations may be challenging, from achieving buy-in from the relevant stakeholders and in the implementation. It will be a wholly new process to will enforce current building codes onto buildings already in existence and may involve establishing trigger points for the enforcement thereof, such as change of ownership. The policy recommendation is to ensure that all new buildings comply with the principles of net-zero carbon design before they are constructed, as it is systematically simpler to implement and roll out. This shift will provide guidance to the market on the requirements for net zero carbon buildings and will provide an impetus to then introduce these requirements retrospectively onto buildings already in existence.

4.1 Introduction

The urgency to transition to a net-zero carbon economy has never been clearer, and the role of the built environment is being increasingly recognised as key to this transition. The vision is ambitious – to have all new buildings we live and work in to be net-zero carbon by 2030, and all buildings by 2050 (C40 Cities, 2018b).

This study looks at the most financially feasible sub-sectors within the building sector using a tool specifically developed for this study, namely, the Net Zero Carbon Energy Efficiency Cost Model. This model explores sub-sectors within the building sector to narrow down the selection of climate change mitigation projects within the Building sector. The cost model accounts for differences in buildings with enhanced energy efficiency and buildings with standard energy efficiency requirements contained within existing building regulations, over a 30year period. These findings will serve as a tool to assist decision-makers in prioritising climate actions that will provide a high abatement potential at the least costs. The objective of this study is to investigate the feasibility of implementing mandatory net-zero carbon principles for new and existing buildings, where the focus is on energy efficiency.

Buildings are where citizens spend most of their time – from the workplace to their residences, learning institutions, and places of worship. Generally, buildings have a life span that can range from 40 to over 100 years and so reducing the output of carbon emissions of buildings from the onset, can offer emissions savings throughout its long lifespan (C40 Cities & McKinsey, 2017). The building sector is one of the largest contributors to global greenhouse gas (GHG) emissions, largely through its energy use where is accounts for around a third of global energy use (ICLEI, 2018). Furthermore, in addition to carbon emissions, the building sector adds other GHGs into the atmosphere such as halocarbons, chlorofluorocarbon, hydrochlorofluorocarbons, and hydrofluorocarbons which are found in some electrical appliances used throughout the operations of some building types (GlobalABC, 2018). It is projected that by 2050 the global population will increase to over 9 billion people, with around 70% of this population living in urban environments (UN-DESA, 2019). This means that there will be a significant demand for new buildings by 2050. There is a positive correlation between levels of urbanisation and GHG emissions. The increased movement of people towards cities will increase the need for development in cities and this will be accompanied by increased levels of GHG emissions in the atmosphere, to which it is estimated that there will be a global GHG increase of 226 $GtCO_2e$ by 2050 (GlobalABC, 2018).

It is estimated by the Global Alliance for Building and Construction that the building sector may be liable for around 28% of global GHG emissions, with a further 11% of emissions arising from the accounting and consideration of embodied emissions from building materials and construction activities (GlobalABC, 2018). Global projections for 2050 show that the floor area in buildings will increase by 100%, equating to over 415 billion m^2 which may potentially increase GHGs (WBCSD, 2018). These projections indicate that population growth will increase by over 20% whereas the floor area will double. The building sector contributes to about a third of global energy use and existing research provides an estimated 28% for its global GHG emissions contribution. (GlobalABC, 2018). These figures refer only to emissions from the operational activities of buildings and are independent of emissions arising from the construction and embodied emissions from building materials and furnishing, which adds a further 11% of global GHG emissions (GlobalABC, 2018). While the building sector as an end-user is a leading contributor to GHG emissions, it is similarly projected that buildings could offer emission reductions of up to 60% by 2050 when utilising energy efficient and renewable energy technologies (GlobalABC, 2018).

For these reasons, four South African cities, namely, the eThekwini Municipality, the City of Cape Town, the City of Johannesburg, and the City of Tshwane, have pledged ambitions of achieving net-zero carbon buildings (both new and existing buildings by 2030 and 2050 respectively) (C40 Cities, 2018a).

Recent research has shown that the building sector, out of all analysed economic sectors in the eThekwini Municipality, dominates the top 25th percentile of marginal abatement costs, which indicates that the building sector should be prioritised for early actions as it represents the most cost-effective sector to reducing the first 25% of the eThekwini Municipality's available life-time mitigation potential (Elias & Thambiran, 2021). This is primarily due to the reduction in energy costs that correlate with reduced energy usage.

The aim of this research is to quantify the role of the building sector in achieving the eThekwini Municipality's climate change goals and to provide guidance towards the development of a strategy that would allow authorities to prioritise actions in addressing climate change within the building sector. The next section of this paper describes the compliance processes that the eThekwini Municipality follows when processing newly constructed buildings with regards only to the energy efficiency aspects, and then delves into the possible processes that would need to be used should existing buildings be held to a similar set of standards. This is followed by a description of the Excel-based cost model "Net-Zero Carbon Buildings Energy Efficiency Cost Comparison" that was developed for use in this project. The key results and findings from the implementation and evaluation of the model results are presented, followed by recommendations for future research.

4.2 Unpacking the role of the building sector: A case study of the eThekwini Municipality

4.2.1 New Buildings

New buildings planned for erection in the eThekwini Municipality requires to comply with the National Building Regulations and Building Standards Act (Act 103 of 1977) (NBR & BS Act) which includes the appointment of a 'competent person' who would be able to guide the homeowner/ developer on the processes for submitting the building plan to the local authority, the implications of failing to comply with the regulations and that of other local authority bylaws and acts and in the eThekwini Municipality as displayed in a high-level diagram in Figure 20, these include, but is not limited to; the eThekwini Municipality: Planning and Land Use Management Second Amendment By-law, 2021, eThekwini Municipality: Stormwater Management By-Law, 2017, and the eThekwini Municipality: Water Supply By-law, 2014 (DTI, 2011 ; ETH, 2021). A high-level overview of the processes involved in submitting a building plan to the eThekwini Municipality is presented in Figure 20 below.

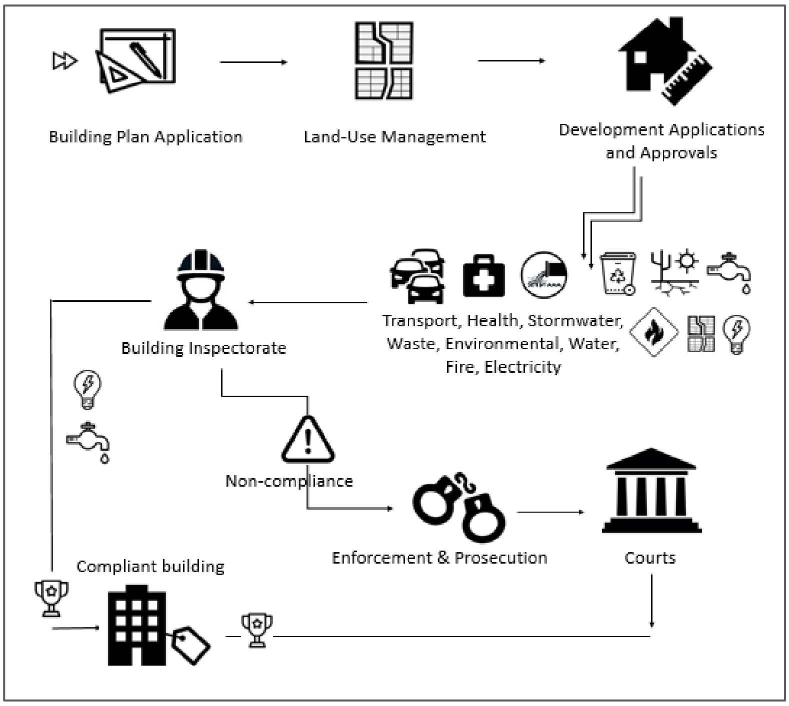


Figure 19: High level overview of processes involved in submitting a building plan to the eThekwini Municipality.

4.2.2 Overview of Existing Buildings

Currently, existing buildings are not required to comply with mandatory energy efficiency requirements, although energy efficiency has become common practice in efforts of reducing electricity bills and reducing the burden on the national grid. In 2018, South Africa's Department of Energy produced draft regulations for public comment that will require all privately owned buildings over 1000m² to visibly display their energy performance through Energy Performance Certificates (EPC). Energy performance can also refer to the energy intensity of a building but is defined in the draft regulation as net energy consumed in kilowatt-hours per square metre per year (kWh/m²/year) (DOE, 2018). Public buildings are included with a threshold of over 2000m² (DOE, 2018). The EPC will aim to make building owners and users cognisant of their impact on energy services and will begin the journey of energy management, which starts with measurement.

There have been other initiatives that aimed to support energy efficiency in existing buildings and a good example is the Private Sector Energy Efficiency (PSEE) programme that was launched in South Africa in 2013 (PSEE, 2016). The PSEE was funded by the Government of the United Kingdom and provided cost-free energy audits to all private sector businesses, to varying degrees. The energy audits provided organisations with a definitive plan to reduce their energy demand and in turn their utility bills (PSEE, 2016).

Existing buildings will require addressing to best achieve a transition to a low carbon economy, and it is recommended that 'deep energy efficiency renovations' will be required for existing buildings (IEA, 2019). While authorities may set building codes for new buildings and ensure that they are adhered to before and during commencement, existing buildings will require some trigger in order for authorities to hold the owner of the building accountable for energy efficiency upgrades. Countries in the European Union, Hong Kong, China, and some states in the USA such as San Francisco include major refurbishments and alterations to comply with mandatory energy efficiency standards (C40 Cities & McKinsey, 2017). Taking a different approach, the City of Austen, Texas in the USA compels multi-unit residential dwellings to report on their energy intensity and to improve their energy efficiency measure should their energy intensity exceeds the benchmark (C40 Cities & McKinsey, 2017). Other trigger points that can be used to ensure energy efficiency on existing buildings may include a change in ownership of the building, change in zoning, or during renovations and upgrades. Unlike building codes for new buildings, these trigger points have not been tested or even tried in South Africa and will be a wholly new process that will enforce building codes onto existing buildings, and may be challenging to get buy-in and for implementation.

South Africa's post-2015 National Energy Efficiency Strategy was released only as a draft but details a plan for long term energy efficiency in the country and includes setting Minimum Energy Performance Standards (MEPS) for technologies and appliances used in buildings such as air-conditioners and refrigerators among other action plans (CER, 2017). MEPS can potentially influence the supply of building equipment and appliances so that energy-efficient equipment is made a preference and informs for the building owner/users of more efficient and affordable equipment when replacing defective or ageing equipment. This approach may be less onerous when cities may not have the direct authority to influence building codes in the context of the National government lagging. In Singapore, as an example, it is nationally legislated that cooling systems and air-conditioners require to comply with energy efficiency performance standards and that a green certification is required on all buildings over 15000m² (C40 Cities & McKinsey, 2017). In developing nations, the rate at which new buildings will be erected is higher than that of developed countries and so it is important to note that the developed world should prioritise improving the efficiency of existing buildings.

4.3 Developing the Model

4.3.1 Modelling approach

To conduct this evaluation an Excel-based cost model was developed for use in this project, entitled the "Net-Zero Carbon Buildings Energy Efficiency Cost Comparison". This tool is based on an input-output model and may also be referred to as a calculator. An input-output model can vary in application and simplicity levels and is often used to assist policy direction as the model quantifies the relationships between different sectors within an economy (Sink, 2010). In this case, the model describes inputs of monetary values to sub-sectors within the building sector and the subsequent value of each sub-sector's outputs. The arithmetic for the setup and calculation does rely heavily on the quality of the data (Sink, 2010). The Net-Zero Carbon Buildings Energy Efficiency Cost Comparison model is structured on the input of the cost of each energy efficiency intervention and then the projected lifetime savings of each intervention. Any amendments or changes to the input data, in conjunction with other data inputs such as the rate of financing and applying a discount rate, may result in different outcomes. Input data for the costs of energy efficiency interventions may not be representative of costs in years' future to the publication of this assessment. It is therefore important for the model to be accessible and editable so that the input data can be refined and updated.

The cost model takes into account differences in lifecycle costs for the seven building types for a 30 year time period in three comparison methods where the first being a standard building constructed with energy efficiency requirements contained within existing building regulations, and the second being a new construction that is built with a 30% energy efficiency over and above the current energy efficiency regulations, and finally buildings already in existence that will be reconfigured or retrofitted with a 30% energy efficiency level greater than the current energy efficiency regulations (DTI, 2011). It is important to note that energy efficiency results in cost savings from reduced energy costs and this study aims to establish the full life cycle costs between energy-efficient buildings when compared to standard buildings.

4.3.2 Methods and Data

The energy efficiency movement has been given great importance in South Africa not only because of climate change requirements but also to reduce the burden placed on the national grid. It is vital that building owners and occupants understand the value proposition of an energy-efficient building, and how energy efficiency may impact their costs over time. Value maximisation is main objective of developers and investors and for the energy efficiency trends in buildings to also thrive, they need to be convinced of the value-adding benefits of these buildings when compared to conventional buildings.

There largely exists a perception that energy efficiency measures cost more than not having any (GBCSA, 2019). This may be true for the initial costs but cost modelling has proven that the life-cycle costs of energy-efficient buildings are more favourable than buildings without energy efficiency measures. As cost is a tremendous concern for authorities and developers, especially in a developing country context, this section will explore cost differences over a period of 30 years between a) a new standard building compliant with the current National Building Regulations (NBRs), b) a new building with energy efficiency levels 30% greater than that of the NBRs, and c) retrofitting an existing building to an energy efficiency level 30% greater than required in the NBRs (DTI, 2011).

To conduct this evaluation in the Excel-based cost model, the "Net-Zero Carbon Buildings Energy Efficiency Cost Comparison" contains data inputs that include base construction costs per building typology, energy intensities per building typology, and electricity costs projected over 30 years. These data inputs are described further in the sub-section below.

4.3.3 Inputs into the Model

Cost for the construction of each assessed building typology forms the basis of input costs in the Net-Zero Carbon Buildings Energy Efficiency Cost Comparison model and refers to the costs incurred by the actual construction and building erection works. Construction costs were taken from AECOM, which publishes these costs annually (AECOM, 2020). The AECOM derived costs, exclude Value Added Tax charges that is currently 15% and further exclude charges from the site development, professional fees for services rendered, which vary per site, and the application of the building (AECOM, 2020). For example, a building that is to be constructed on a steep slope will incur different charges to one being constructed on flat terrain. These exclusions do not impact the results of this study as the differences in costs must be done on a like-for-like basis.

Further to construction costs, electricity costs as determined per building typology using energy intensity values obtained from the existing NBRs, and an annual price increase of 8% is applied (DTI, 2011 ; ESKOM, 2020). The 8% is taken using the average tariff price increase from Eskom for the residential and commercial sub-sectors for the years 2012/13 to 2018/19 (ESKOM, 2020). Standard buildings refer to buildings that comply with the current energy-efficient building codes from part XA of South Africa's NBRs (DTI, 2011). Therefore the construction costs, energy demands, and energy costs can describe the cost of a standard building. When looking at the full life costs of a new building that is 30% more energy efficient than the current regulations, a cost premium is added for the extra energy efficiency interventions. Organisations such as the Green Building Council of South Africa have published findings on cost premiums for green buildings in South Africa (GBCSA, 2019). This model is guided by the GBCSA characterisation that a highly energy efficient building incurs an 8.4% building financial premium when compared to standard construction costs and offers a 30% proportion reduction in building electricity consumption compared to a standard building (GBCSA, 2019). The required increase in energy efficiency is derived from the draft update to the NBRs published in 2020 that is set to replace the current regulations published in 2011 (SABS, 2020). The Draft application of the National Building Regulations *Part X: Environmental sustainability Part XA: Energy Usage in Buildings* is moving towards the goal of a highly energy-efficient building that aims towards achieving a net-zero carbon status (SABS, 2020). For the final cost comparison, the model describes the full life cost for retrofitting an existing building to be 30% more energy efficient than the current standard (i.e. a building that was built before the 2011 energy efficiency regulations). The input data used for this study was derived from a range of sources, including the local market and national market rates. National market rates for technical interventions were obtained from South Africa's National Mitigation Potential Analyses, with more recent costs obtained from the Department of Forestry, Fisheries, and Environment. Further to this, local costings for the retrofitting interventions were obtained from existing research for the municipality to provide a more localised and specific context (DEA, 2016; ETH, 2017). The reduction in electricity consumption is modelled to have an improved efficiency of 30% compared to that of a standard building.

The costs of construction have a finance charge of 11% over 30 years, with a discount rate of 7% being applied. Finance charges refer to the cost of obtaining credit over a time period and in this context, the discount rate refers to the time value of money, and determines the present value of the money over 20 years of financing. It is important to note that the model demonstrates high sensitivity to the lending rate and this implies that there may be a strong case to motivate for climate financing at lower rates to catalyse the market for energy efficiency, and for future renewable energy installations, in buildings.

The model is thus based on primary input costs that include the construction costs, energy demands, and energy costs which all feed into the base costs for each building typology. As the model evaluates costs over a 30 year period, the finance charges, discount rates, and increases in energy costs are applied to each building typology throughout the 30 year period. This allows for a consistent and reliable comparison of the projected costs for each building typology under the differing energy efficiency profiles. When reading the graphical results of the model, it is important to note that year 1out of 30 refers to the first year of the building's existence, taking into account the base costs of the buildings. As the costs for standard buildings with standard energy efficiency are the current benchmark for costs, the point of breakeven may be described as to when the buildings with enhanced energy efficiency achieve a lower cost to the standard building costs. For ease of reference, hereafter, new buildings with enhanced energy efficiency will be described as a 'new green building' and existing buildings that have been retrofitted with enhanced energy efficiency will be described as a 'retrofit green building'.

4.3.4 Assessed Building Typologies

A building is defined as a man-made structure that may be classified into typologies based on its occupancy and type of construction (DTI, 2011). All buildings have fundamental commonalities that include the need for strong design, engineering, construction, and management when the structure is completed. However, the approach to the design, engineering, construction, and management of individual buildings will significantly differ based on the application of the building and what it is purposed for. Therefore it is important that each building be designed appropriately and a model cannot be indiscriminately applied to all buildings within a sub-sector. In describing the energy profile of buildings, using the sub-sectors of residential and commercial can provide general ideas of how the building will consume energy (GBCSA, 2019). A distinction is further made between new buildings and existing buildings due to technical and financial differences between constructing buildings as energy-efficient and then retrofitting an existing building to improve energy efficiency. The residential sub-sectors can be further disaggregated as per the level of affluence while the commercial sector is based on its application. It is for this reason that seven building types are being assessed, with the aim of providing an indication of the comparative lifecycle costs of energy efficiency interventions in each building subsector.

Building typologies included in this cost analysis are summarised below in Table 4 and are adapted from section A20 of part XA of the NBRs (DTI, 2011). The building typologies have been analysed to display buildings constructed according to energy efficiency requirements contained within existing building regulations new constructions that are built with a 30% energy efficiency over and above the current energy efficiency gains, and buildings already in existence that will be reconfigured or retrofitted with a 30% energy efficiency level greater than the current energy efficiency regulations.

Table 2: Summary of building typologies used in cost analysis.

Sector	Building Typology	Description
Residential	**Housing**	
	Low cost house	Affordable, simple structures for lower income categories.
	Middle Income house	Housing structures for middle income population.
Commercial	**Offices**	
	Low Rise office park	Places of work such as banks.
	High Rise office block	Buildings comprising of more than 4 stories or that have a height of more than 15 meters above the ground (DTI, 2011).
	Retail	
	Convenience Store	Local consumer staples store.
	Shopping Centres	Retail centers with a minimum of 25000 meter squared.
Educational	**Schools**	
	Primary & Secondary Schools	Buildings of instructional, educational and recreational activities (DTI, 2011).

4.3.5 Limitations of Model

The Net Zero Carbon Buildings Energy Efficiency Cost Comparison model is based on a simple input-output model and thus is limited to reporting on the gross impacts or the bottom line impacts arising from implementing energy efficiency interventions. There are many other external economic and environmental influences that should be considered by decision-makers, such as the impacts of energy efficiency to job creation, improvements to grid reliability, reduction of point-of-source water from use in power generation, and possible changes in land use. Some negative impacts may include displacement of the local electricity supply model and the impacts that the higher initial costs required for energy efficiency may have on the residential and commercial sectors in the Municipality. Additionally, this model does not account for the impacts of a city-wide improvement in the demand for energy efficiency interventions and how this would impact the cost of these interventions.

4.4 Cost Comparison of energy efficiency interventions in new and existing buildings in the eThekwini Municipality

4.4.1 Residential: Housing

The model looks at the costs for each building type over a 30 year period and establishes when the increase in costs for energy efficiency intervention will break even based on the savings from energy efficiency. In this study, the point of breakeven is also described through defining the payback period. The payback period is the length of time that an investment takes to recover the cost of an investment, where a positive payback period means that the investment has recovered its costs and is now showing a positive financial case going forward (Paltrinieri & Khan, 2016).

Year 1 will refer to the first year of the building's existence, taking into account the base costs of the buildings. As the costs for a standard building is the current benchmark for costs with standard energy efficiency, the point of breakeven may be described as to when the buildings with enhanced energy efficiency (listed on the graphs as new and retrofit 'green buildings') achieve a lower cost to the standard building costs. Figure 21 highlights the life cycle costs for low-income dwellings, where the break-even point for energy efficiency interventions is not met within the assessed 30 years. This may be attributed to the low electricity usage within low income households. To then retrofit energy efficiency measures onto this building type will cause a further increase in the cost wherein the payback is lengthy. In this case, it can be noted that energy efficiency should be incorporated into the design of a new building, rather than be retrofitted in order to save costs.

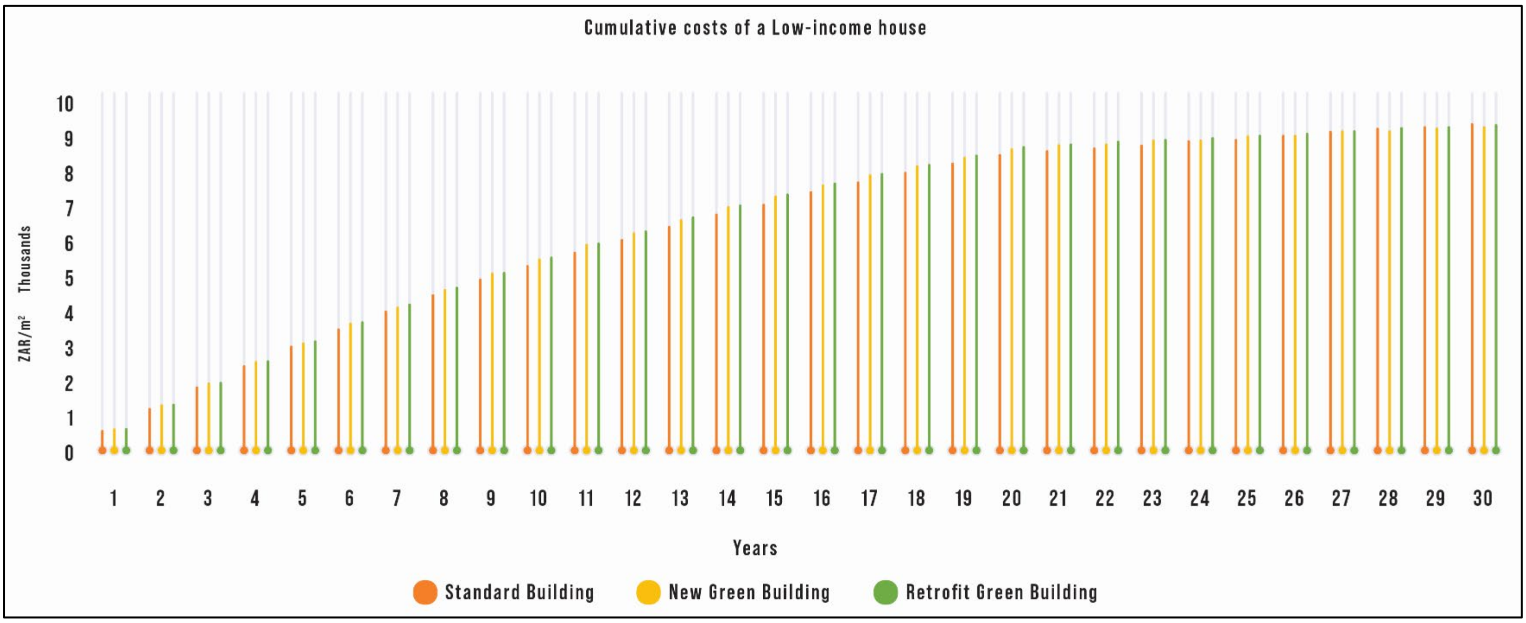


Figure 20: Cumulative discounted costs for low-income residential buildings, consisting of construction and energy efficiency interventions.

It could be argued that based on lifecycle costs that the current energy efficiency codes in the current NBRs are sufficient for this building type. However, then issues of inclusivity may arise as energy efficiency has benefits of more affordable living. Apart from costs, there are numerous other benefits to energy efficiency such as improved thermal comfort and indirect water conservation. Decision-makers should strive to afford energy efficiency interventions to low-income houses, as well as other resource-efficient interventions like locating the households close to transport nodes and motivating for rainwater harvesting and green spaces.

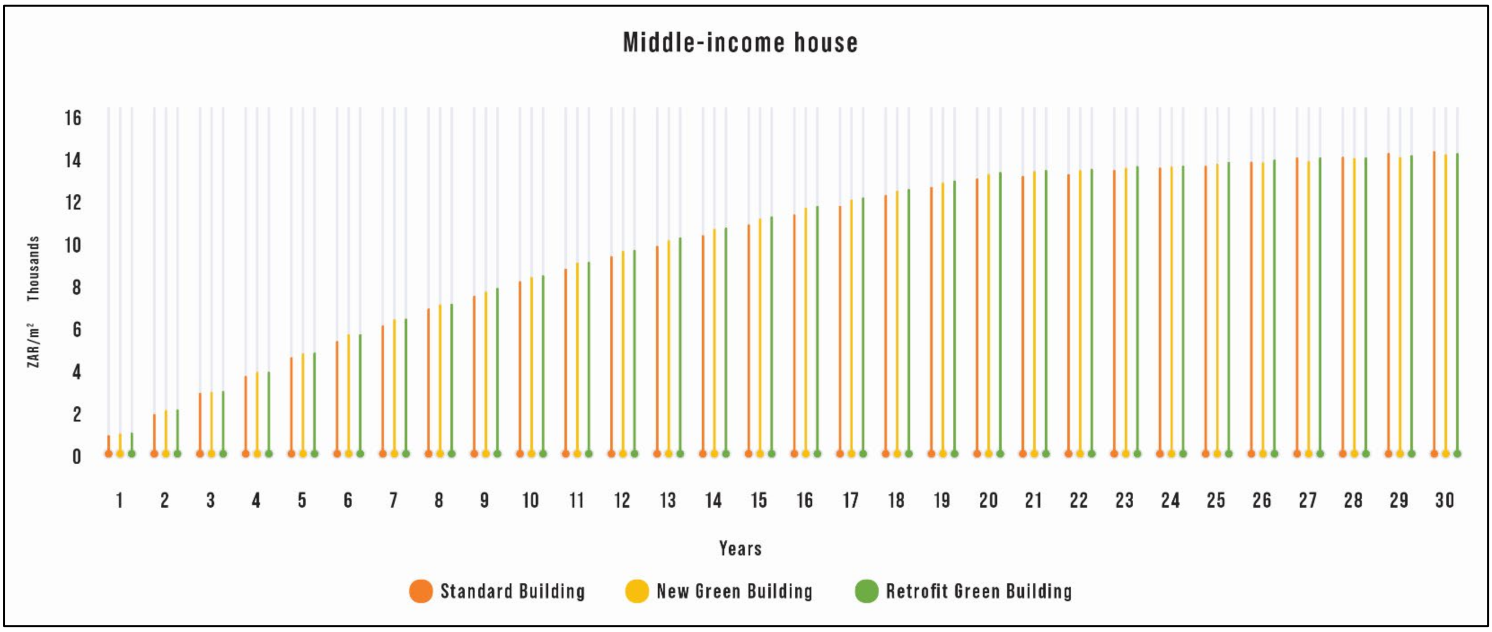


Figure 21: Cumulative discounted costs for middle-income residential buildings, consisting of construction and energy efficiency interventions.

As with low-income households, the bottom-line case for energy efficiency in middle-income houses remains unconvincing. Referring to Figure 22, Year 26 shows a new green building to have lower costs than that of a standard building. It is only Year 29 of a middle-income house that has been retrofitted with energy efficiency measures shows a positive financial case when compared to a standard building, as shown in Figure 22.

However it must be noted that residents also do value energy efficiency and energy-saving behaviours in order to keep electricity bills low. When affordability is less of an issue, households even strive to supplement their power with renewable energy in the attempts of becoming independent from the National Grid. Again, it must be noted that there are various other benefits to improving the energy efficiency within homes and despite a longer time frame of payback, it is the author's opinion that most middle to high-income houses do invest in energy efficiency.

4.4.2 Commercial – Offices and Retail

To read the graph, it is important to remember that the model looks at the costs for each building type over a 30 year period and that year 1 will refer to the first year of the building's existence, taking into account the base costs of the buildings. As the costs for a standard building are the current benchmark for costs, the point of breakeven may be described as the year that the energy-efficient buildings realise a lower cost than that of the standard building.

The electricity usage and the time of electricity use vary between residential and commercial buildings. A generalised understanding of commercial buildings would tend to have a higher occupancy throughout the day and lower occupancy at nights, using usual working hours of 08h00 to 17h00. Commercial buildings would typically consume more electricity due to the higher occupancy and more energy-intensive equipment, amongst other factors, and also the electricity tariff for commercial buildings is higher than that of residential buildings (ESKOM,

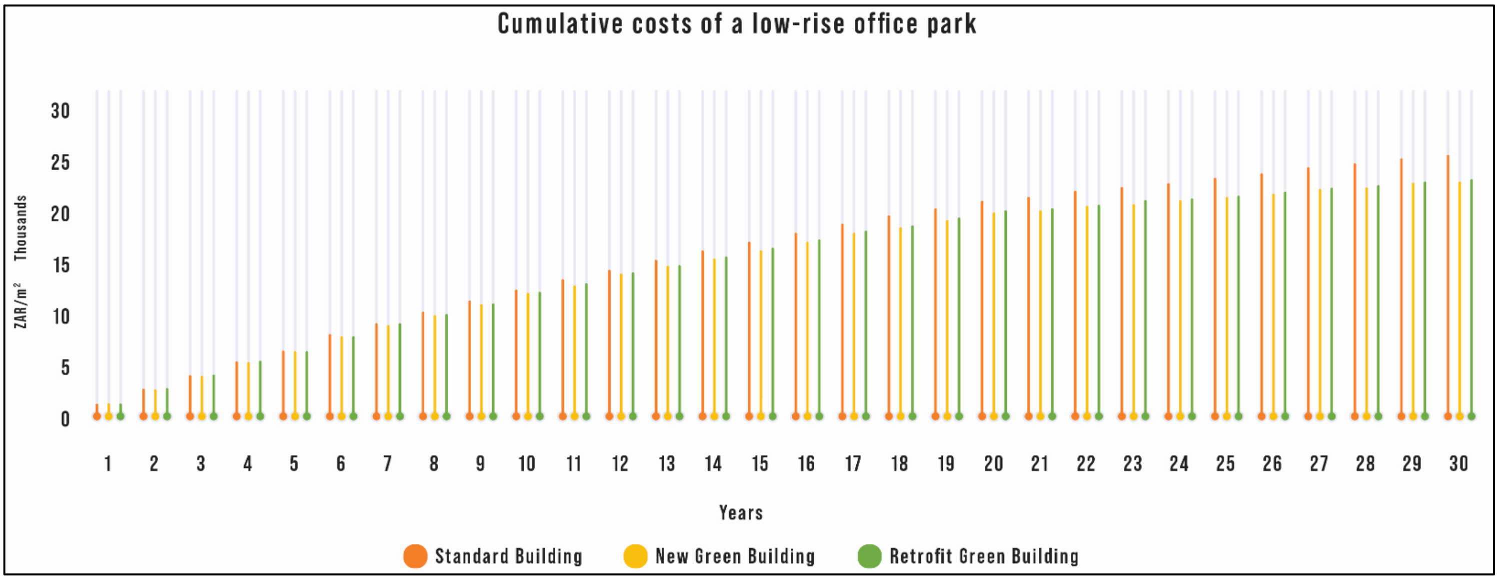


Figure 22: Cumulative discounted costs for a low rise office building, consisting of construction and energy efficiency interventions.

2020). This means a more favourable financial outlook for implementing energy efficiency measures in commercial buildings. Additionally, commercial institutions are motivated to boost the productivity of their staff and this can be achieved through improving the thermal comfort, quality of lighting, and ensuring adequate ventilation and air quality in the buildings. Energy efficiency measures can touch on all of these aspects, making energy efficiency an appealing option for commercial buildings.

Figure 23 showcases a low-rise office block that reaches break even on year 2 both new green and retrofit green buildings in terms of bottom line calculations. Designing a building from the onset as energy-efficient is still more cost-effective as the return on the investment is higher in the new buildings, however, the business case for even retrofitting energy efficiency is just as compelling.

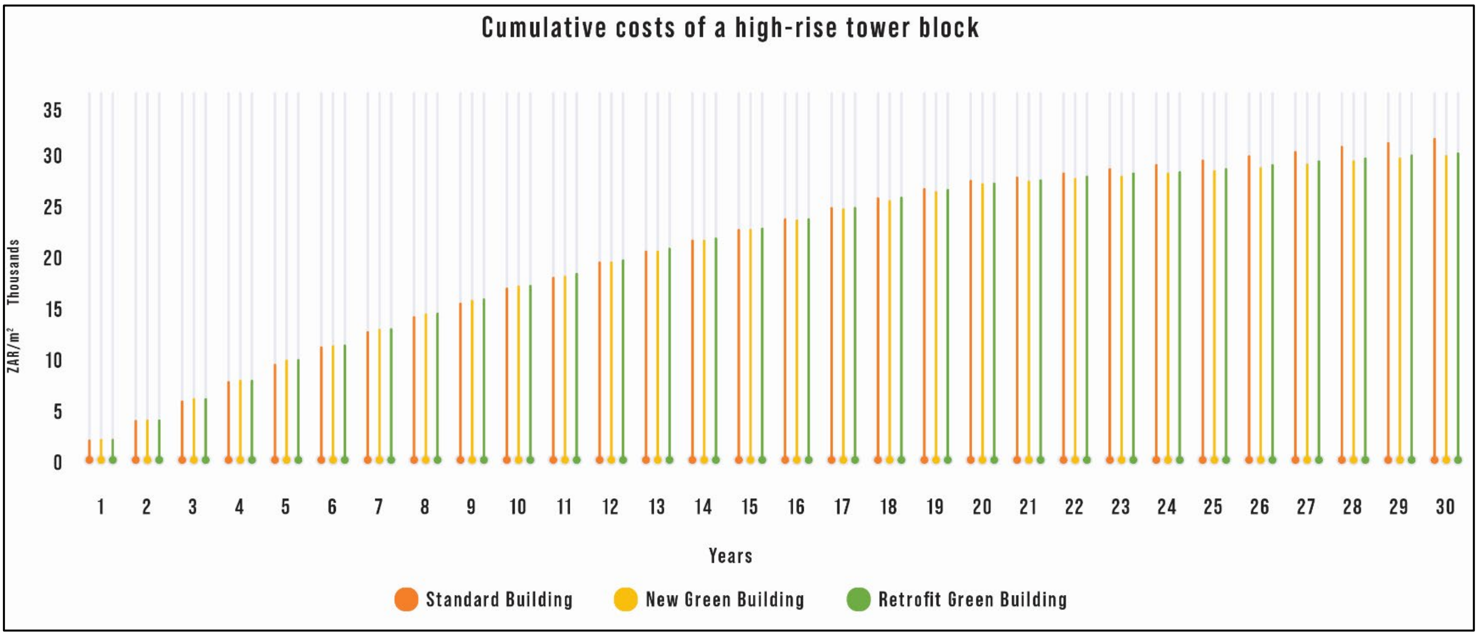


Figure 23: Cumulative discounted costs for a high rise office building, consisting of construction and energy efficiency interventions.

Interestingly, the data shows that a different case for high-rise office blocks in Figure 24 where a payback for designing and building a new green building attains payback on year 15 when compared to a standard building, and the retrofit green buildings reach a break-even point on year 18. Based on input data from the model, the electricity costs and costs of construction are significantly higher in a high-rise building. International research corroborates this phenomenon, showing that energy use significantly increases per square meter in a high rise building when compared to a low-rise building and that the carbon emissions are about double per meter square from a high-rise building (UCL, 2017). According to research from the University College London, the same applies to high rise residential buildings (UCL, 2017).

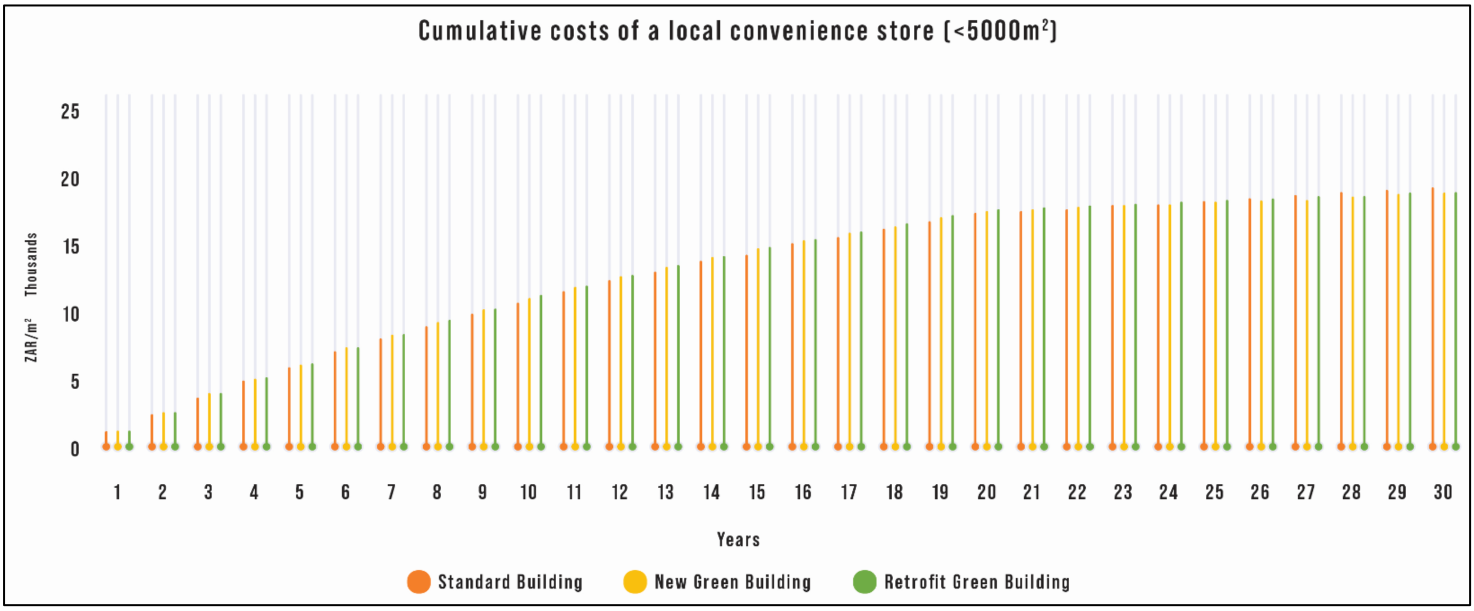


Figure 24: Cumulative discounted costs for a local convenience store, consisting of construction and energy efficiency interventions.

The profile of the convenience store used for this model, shown in Figure 25, is a convenience store of less than 5000m². The electricity profiles are taken from the ranges within South Africa's current building regulations. A convenience store of this size would typically sell consumer staple items and where energy use would be in lighting, refrigeration, and even cooking. While energy efficiency interventions reduce the electricity consumption in a convenience store, the cost of construction and designing the building with efficiency in mind (new green building) causes the payback for an energy-efficient building to be achieved in year 24. A convenience store that is retrofitted to be energy efficient (retrofit green building) will break even at year 27 when compared to a standard building.

Offering a contrast in Figure 26, a shopping mall that is over 25000m² shows an immediate saving in cost for both new green buildings and retrofit green buildings that are energy efficient when compared to a shopping mall with standard efficiencies. While construction costs are typically higher when designing for energy efficiency in buildings, for shopping centres the electricity savings far exceed the initial costs resulting in payback within the first year. It is beneficial even for existing shopping centres to enhance their existing energy efficiency measures. Further to cost-saving, energy efficiency creates a more conducive atmosphere for shoppers and there is an associated value to a brand when a clear consideration to the environment and well-being for the planet is made.

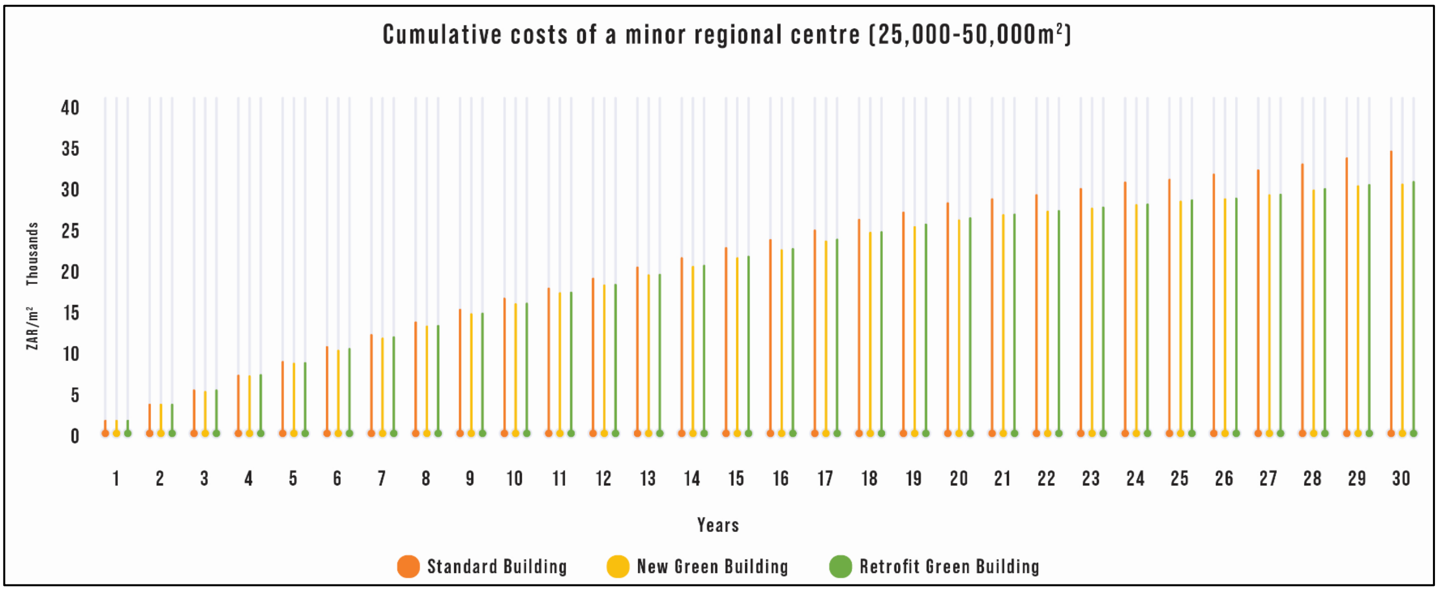
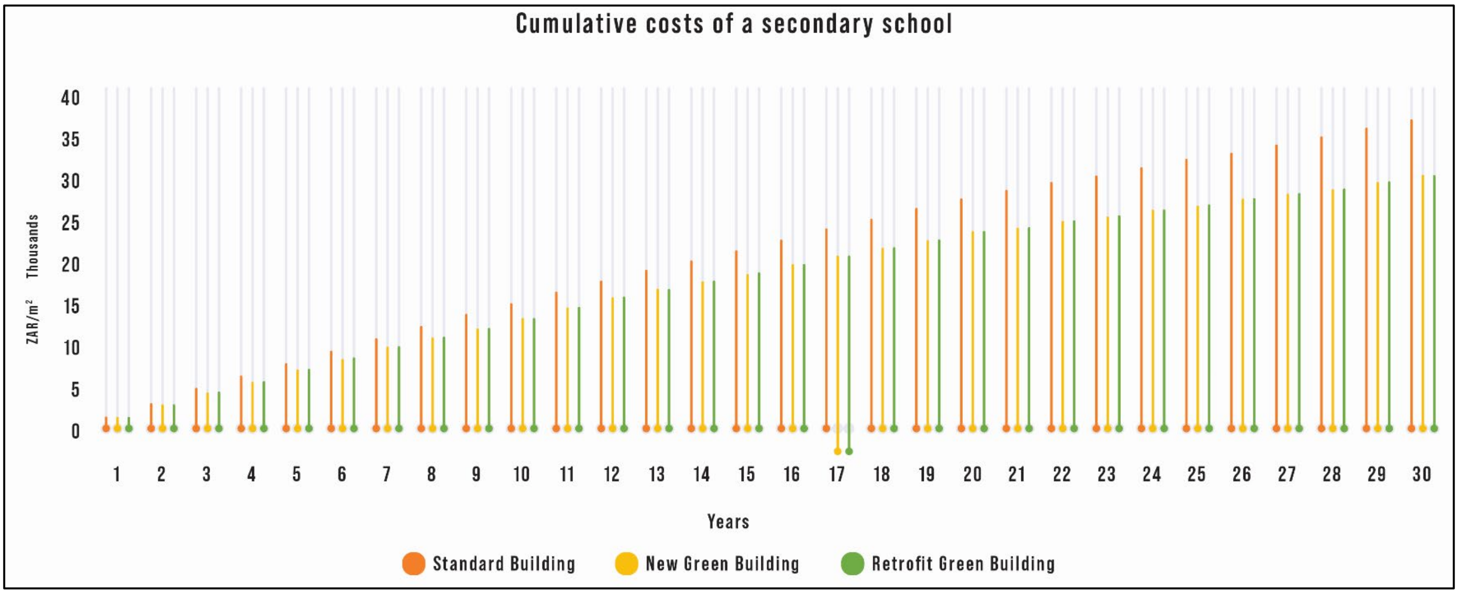


Figure 25: Cumulative discounted costs for a shopping mall, consisting of construction and energy efficiency interventions.

The last of the analyses included looking at both primary and secondary schools and the impacts that energy efficiency would have on the cost of construction and from retrofitting. Figure 27 shows an average of primary and secondary schools, which are both favourable to new green buildings and retrofit green buildings. Secondary schools typically have a higher energy usage than primary schools due to their increased use of information and communications technologies (ICT) and laboratories for science (DTI, 2011). However, the business case is financially positive for both schooling types for both new and existing buildings, with payback being reached in the first year. It is important to note that while energy efficiency measures in schools have a positive financial impact, there are also the advantages



of students being able to practically understand energy efficiency by having a first-hand example of it in their classrooms.

Figure 26: Cumulative discounted costs for a school block, both Primary and Secondary schools, consisting of construction and energy efficiency interventions

4.5 Discussion of Results

Most existing buildings were not designed with the consideration of energy efficiency standards however, this model assumes that all existing building complies with the current energy efficiency regulations and so it may be that the electricity savings are higher in existing buildings. It is however implicit that existing buildings will be more challenging to address than new buildings because of the extra cost of retrofitting, and also the legal challenges of holding existing property owners retrospectively to new legislative requirements. While an important component of the building sector, it would be legally challenging for authorities, who would need to find an innovative way of enforcing new requirements onto building owners to make them accountable for assets that are already in existence and possibly in use. Nevertheless, existing buildings will remain the bulk of the building sector and cannot be ignored in climate change mitigation responses. It is however incumbent that mitigation responses be prioritised according to its feasibility and ease of implementation.

Figure 28 is a summarised display of the analysed building typologies and their cumulative lifecycle costs and electricity usage based on their efficiency level at 15 years, which is the halfway point of the assessed period. The efficiency level of a building designed with energy efficiency and a building retrofitted to accommodate for energy efficiency is assumed to be the same. It is interesting to note that in all cases, the initial costs for construction of an energy-efficient building is higher than that of a standard building. However, when looked at in its entirety or the life cycle of the building, the model illustrates when the building reaches its payback period through savings from utility bills. This is notable for shopping centres and schools blocks that show a positive financial payback period based on the savings from energy costs within the first 2 years. Electricity use and its savings with energy efficiency interventions differ based on the application of the building type, and this is reflected in the savings in electricity usage in each building typology.

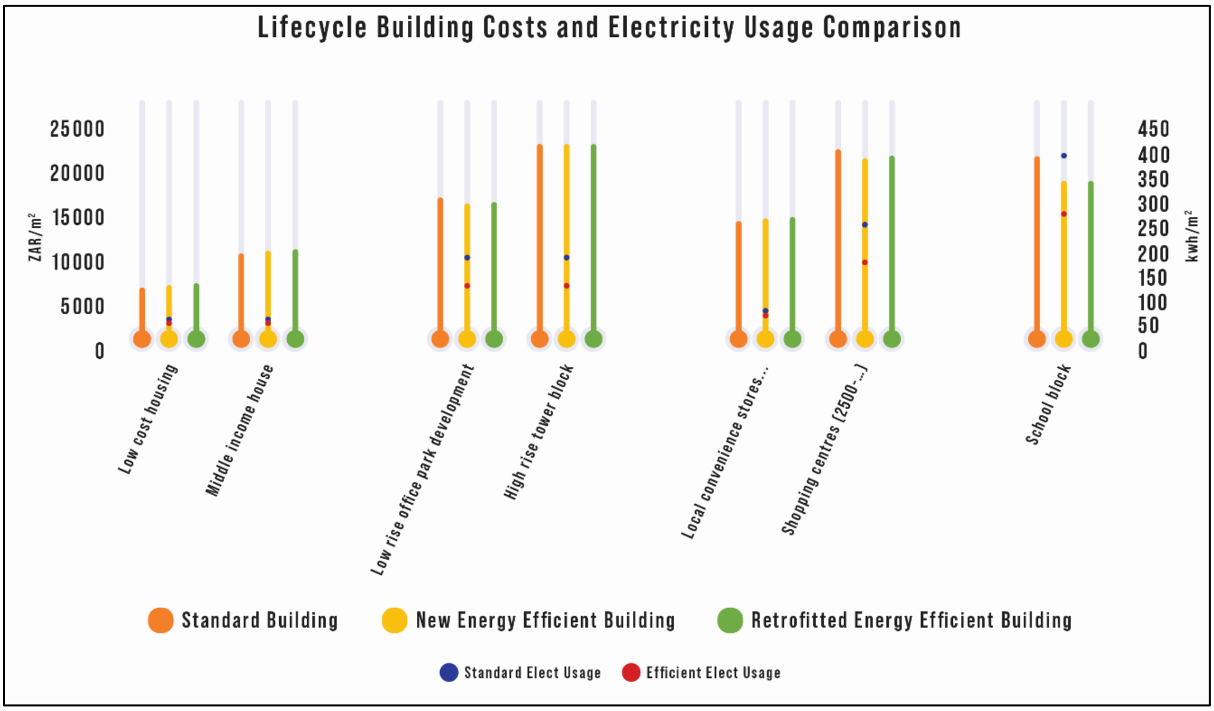


Figure 27: Summarised look at construction costs and electricity usage per building type and efficiency levels at year 15.

As new buildings are projected to grow by about 40% by 2050, new buildings should be an important focus as the rapid erection of inefficient buildings could limit the potential of GHG reductions whereas the development of highly energy-efficient buildings that are ready for the renewable energy aspect of a net-zero carbon building will significantly reduce GHGs from the building sector into the future (C40 Cities, 2019b). Notwithstanding the future mitigation potential of the new building sector, it is simpler to implement stringent energy efficiency standards before a building is constructed, and local authorities could "piggy back" on existing regulations. Furthermore, it is indeed more affordable to build with efficiency in mind than it is to retrospectively upgrade the building to be efficient.

However, this study notes that the subsector of new buildings represents less than half of the potential of the building sector. Existing buildings, however complex, cannot be ignored. The urgency of climate change and the need for GHG reduction compels authorities to innovate and rethink the way business is conducted. The purpose of life cycle modelling is to estimate the costs that would be spent on an asset throughout its useful life, and in identifying the financially positive cases for retrofitting existing buildings, decision-makers can plan a phased approach to decarbonising the building stock.

Based on the outcomes of the model, the following building types display a strong business case for retrofitting energy efficiency; low rise office blocks, shopping malls, and school blocks. These building types show a payback period of fewer than two years for retrofitted energy efficiency which is a viable payback period similar to that of new buildings.

The cost model further allows one to adjust input variables, and attention may be given to the financing rate. As the issues arising from change will be a shared one, the private sector may be amenable to working closely with governments in order to reduce the worst risks of the future climate. There is therefore an opportunity to motivate financial institutions to lower the financing rate for energy efficiency measures on buildings that would allow for a more compelling business case, especially for the building typologies that have a longer payback period. Energy efficiency will not only benefit the occupants and climate mitigation efforts but will serve to ensure that the building stock in urban areas maintains their asset value, in the face of a world moving increasingly towards 'green' trends and climate politics.

4.6. Conclusions and recommendations

Buildings as structures last for well beyond a hundred years, and therefore constructing these buildings to be net-zero carbon from the on-set will ensure that the building stock of the future is a low carbon one. The building sector is integral to people's safety and living but also provides spaces for the workforce, economic activity, and innovation. Investments into the safety, comfort, and even aesthetics for all building types is natural, with many cities being famous for some iconic buildings and structures. While buildings are immovable, fixed properties, the energy behaviours and demands of its occupants vary. Drivers for energy use in buildings are dependent on various factors that would stimulate the usage of energy and includes climate and weather, economic growth, cost of energy, and regulations. This study brings forward energy efficiency as a vital component to reducing climate change, as energy efficiency interventions in buildings offer substantial mitigation potential within the most feasible payback periods when compared to other sectors.

The built environment is a critical part of the climate change problem in cities and urban buildings can act as a scaled response to mitigating anthropogenic climate change. Further, buildings may also act as a scaled solution to improving urban resilience in the face of growing populations and impending pressures from climate change such as extreme weather events. Erecting structures and buildings that are resilient to future climate pressures will provide cities with a healthier and safer environment for urban dwellers.

The building sector is made up of various stakeholders and role-players whose buy-in and input are required to successfully implement net-zero carbon objectives within the building industry. A key part of the net-zero carbon objectives relies on enhancing the energy efficiency within buildings so that the building is a high performing one. For buy-in to be obtained from these parties, there is a need to understand energy efficiency in buildings better, particularly the efficiencies that can be achieved, and there needs to be motivation in the form of costs. This study aimed to investigate the value-adding components of highly energy-efficient buildings in South Africa as a precursor to net zero carbon buildings.

There exist various aspects to assessing the feasibility of processes for GHG abatement and policy responses, but this study remains focussed on the bottom line financial implications of abatement measures within the building sector. It is important for the continued existence and growth of energy efficiency measures within the building industry that the various solutions be defined, the cost is differentiated and understood by all stakeholders in the market. This is especially true for net-zero carbon buildings, as the cost will be the primary driver behind development and investment in the uptake of the sector.

4.6.1 The Building Sector is key to transitioning to a low carbon economy

The determination of the eThekwini Municipality's GHG mitigation potential conducted for the CAP provided a key departure point for the development of the MACC for emissions reductions forecasts within the municipality. Based on the MACC, the buildings sector offers the lowest cost to reduce GHG emissions when compared to the other studied sectors. Several interventions within the building sector display negative costs, indicating that the intervention will have a positive payback period throughout its lifecycle. The building sector, out of all analysed economic sectors in the eThekwini Municipality, dominates the first percentile of abatement costs that refers to the lowest cost interventions. This indicates that the building sector should be prioritised for early actions as it represents the most cost-effective sector to reducing the first 25% of the eThekwini Municipality's available lifetime mitigation potential. All interventions to reduce GHG emissions up to 2050, in the building sector provides a return on investment. The intervention with the lowest costs is the installation of efficient LED lighting in both new and existing buildings for both the national MACC and for the MACC developed for the eThekwini Municipality in this paper (DEA, 2016).

The waste sector has the second lowest abatement costs in the eThekwini Municipality. The transportation sector displays the highest abatement power across all assessed sectors for the eThekwini Municipality, and this is followed by the power sector. The low costs for the waste sector largely arises from the revenue generated through the resale of the waste material and also for reducing the costs associated with landfilling, where there are costs to landfill in the eThekwini Municipality and in South Africa. The waste sector represents the sector with the third lowest cost for the national MACC but this is due to the consideration of the AFLOU sector in the national MACC that was not accounted for in the CAP (DEA, 2016; C40 Cities, 2019a). It is important to note that a MACC is not meant to be the final deciding factor for policy makers, but that it does add to an important basket of factors that need to be considered when planning for future climates in cities.

With the understanding that the building sector is the sector that offers a high abatement potential at the lowest cost, the prioritisation of the building sector in the City's climate change mitigation planning should take precedence. It is then important to detail the specific actions that are required to be implemented within this sector, and the prioritisation of such. The research identified various factors that differentiated the building sector from other sectors of the economy while highlighting that the potential for mitigation in the building sector is worth considering in plans to address and mitigate climate change. The drivers and trends behind these factors have been unpacked and it is undoubtedly clear that the building sector should be prioritised as a key action for the eThekwini Municipality in efforts of reducing GHG emissions. Further to this, it is noted that the developmental challenges faced by the eThekwini Municipality mean that any financial implications would need to be addressed, as decision-makers require to substantiate investments. It has been documented that the building sector can provide the most amount of emissions reductions at the lowest cost in comparison to any other sector, and it became important to corroborate this research specific to the local context of the municipality. The development of a focussed plan within the building sector is necessary for implementation as there exist subsectors of new buildings and existing buildings that have different dynamics to GHG reduction, in all building typologies.

It is important in strategic planning to identify the actions required and the financial implication of each action, to facilitate the most appropriate investment into implementation. The aim of this research focussed on evaluating the life cycle cost differences of new and existing buildings for the first and most fundamental step to achieving a net-zero carbon building – energy efficiency. A building would need to achieve the maximum efficiency gains before supplementing its remaining energy use with renewable energy to ensure that the system size of the selected renewable energy sources is optimal. Existing buildings in the eThekwini Municipality were largely not designed with energy efficiency in mind and will require deep retrofitting to attain the energy efficiency standards that could be achieved in the design of new buildings.

4.6.2 Recommendations and Way Forward

This study proves that the building sector offers a high mitigation potential at the lowest cost when compared to other economic sectors in the eThekwini Municipality (Elias and Thambiran, 2021). While this study prioritises climate action and focuses on the building sector, this study further delves into the detail on the financial implications of the various pathways that can be taken within the building sector.

The cost differences for continuing business as usual and in implementing stringent energy efficiency measures onto buildings show a positive business case for certain building typologies in the commercial and educational spaces, for both new and existing buildings.

This study focuses on the total life cycle of various building typologies, with a uniquely developed model that illustrates when the building reaches its payback period through savings from utility bills. Electricity use and its savings with energy efficiency interventions differ based on the application of the building type, and this is reflected in the savings in electricity usage in each building typology.

A low-rise office block shows that energy-efficient buildings offer a lower per meter square cost in year three. The high-rise office block shows a less compelling case in the limited terms of financial feasibility but still shows an overall lower life cycle cost, with the energy-efficient option becoming financially feasible in year 15.

The business case for energy-efficient buildings in the shopping centres over 25000m² is extremely strong, with the energy-efficient types becoming more cost-effective in the first year. This finding is encouraging for the for property developers of shopping centres to invest in both new and retrofitting shopping centers to be net zero carbon, where a positive financial payback period based on the savings from energy costs within the first 2 years. Contrastingly, the business case for energy efficiency becomes less so in smaller convenience stores with the financial positive benefit not showing in a 15 year time frame but displaying in year 24. School blocks also display a convincing financial motivation for energy efficiency as interventions on both new and existing building types show a lower cost from year 1. Government departments in charge of school blocks should plan to build all new school blocks to be net-zero carbon and should plan to retrofit existing school blocks, for the benefit of emissions reductions and reduced expenditure.

Should the Municipality begin implementing energy efficiency interventions within the building sector, it should be noted that there are differences in the financial feasibility across building typologies, and buildings that display a more financially positive case will need less motivation for these interventions. However, financial feasibility is not the only factor for consideration in achieving the 2050 target, as per the NDP that the building sector should be net-zero carbon. Based on the cost analyses for various typologies within the buildings sub-sector, a phased approach to address the building sector can be applied, where the 'easy wins' of financially positive building types can be applied.

In the case of the residential market, it may be worthwhile to investigate financing options to assist these markets with the initial extra costs associated with energy efficiencies. There are additional approaches that local authorities can consider such as influencing the supply of technologies (that are highly energy efficient only), or by offering competitive financing rates to building owners or tenants who undergo energy-efficient retrofits. Awareness-raising on the benefits of reducing GHGs may also assist in achieving buy-in.

Addressing GHG reductions in the building sector is wholly important to climate change mitigation, and that net-zero carbon requirements for new buildings may be implemented with less complexities than existing buildings, it makes strategic sense to work on enabling a regulatory environment that would ensure that all new buildings operate at a net-zero carbon status by 2030. As current energy efficiency standards do exist for new buildings, local authorities can increase the stringency of the standard in efforts of creating a healthy and habitable city for its residents.

Within the building sector, new buildings across building typologies will offer efficiencies at a marginally lower cost than that of retrofitting existing buildings to be efficient. It may be less challenging and more cost-effective to take on the commitment of ensuring that new buildings become net-zero carbon by 2030 but existing buildings cannot be neglected if the eThekwini Municipality aims to achieve the emissions reductions within the building sector that are required by science.

Existing buildings make up the bulk of the building stock with models showing that existing buildings will make up about 70% of the building stock in the eThekwini Municipality in 2030 (C40 Cities, 2019b). Therefore, existing buildings have a significant role to play in climate change mitigation and also in ensuring safe and affordable energy access for all.

It is recommended that a phased approach be taken to address the different building typologies based on their financial outlooks. Buildings, such as low-rise offices, shopping centres, and schools, that display a financially positive bottom-line case should be targeted first, as long as there is adequate communication and marketing of the cost-benefit analyses associated with net-zero carbon buildings. It will be important to prepare the market in the understanding of net-zero carbon and its benefits, along with the implementation of a favourable regulatory environment for net-zero carbon building requirements. As local authorities must be cognisant of regulations that the National Government will implement, there will be the opportunity to complement and work with national regulations that also promote enhanced energy efficiency and net-zero carbon buildings. One such example of this would be 2018's draft regulations for the Mandatory Display and Submission of Energy Performance Certificates for Buildings published by the Minister of Energy for public comment (DOE, 2018). The draft Regulations propose the introduction of mandatory requirements for the display of energy performance certificates in non-residential buildings (private and state-owned).

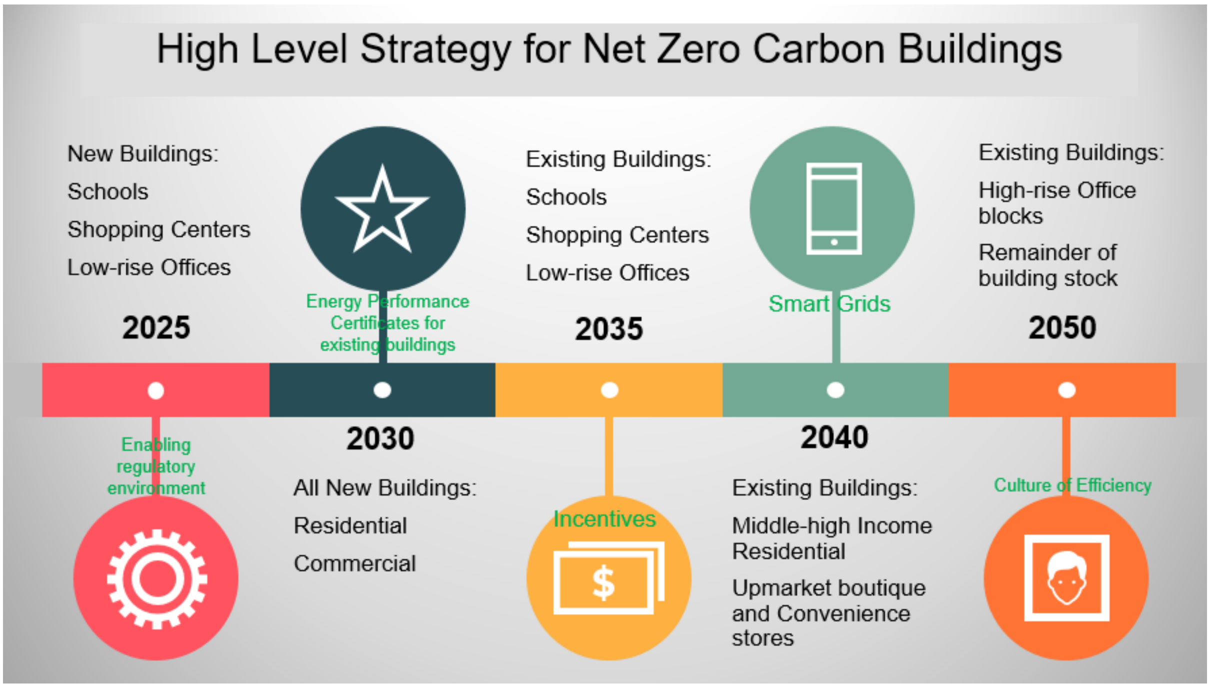


Figure 28: Recommendations for Taking Climate Action in the Building Sector of the eThekwini Municipality

As always, the details of the implementation plan will determine the success of such a ground-breaking climate change mitigation strategy in a developing city context. Robust and inclusive consultations, engagement, and awareness drives will be vital to ensure complete buy-in, not only from private sectors but also from municipal-owned property occupants. A phased approach can prepare the market and allow for sub-sectors to budget and plan for a low-carbon of conducting business and for safer ways of living. Due to ease of implementation, it is recommended that new buildings be phased in first, with the financially positive cases to be implemented in first, thereafter followed by the less compelling buildings in 2030 like that in the residential sector, high-rise offices, and convenience stores. As illustrated in Figure 29, this approach will enable the Municipality to achieve its 2030 target of having all new buildings to be built as net-zero carbon. A similar pattern can be followed for the existing building sector, going up to 2050, bearing in mind that different legal approaches and triggers will be required to retrospectively hold building owners accountable for their emissions from building assets.

New buildings should be prioritised before existing buildings, as per Figure 29, due to the complexities of holding existing properties retrospectively responsible for additional requirements and for potential complications in the installation of renewable energy due to the building's structural integrity and space limitations that may apply to its dense surrounding areas. Renewable energy can become a sizeable investment and energy efficiency will ensure against over expenditure on renewable energy, and a smaller renewable system would take up less space. Energy intensities contextualises the Kilowatt-hour consumption for every meter square of a building, allowing for a fair comparison of the various building typologies that can be a new or existing building. While it may sound obvious that an existing building would incur more costs due to the service costs of retrofitting high energy-consuming technologies with efficient technologies, it is important to understand how these costs play out in the life cycle of the specific building type. As it is noted that both new and existing buildings are a vital part of the puzzle for achieving science-based GHG reductions, the prioritisation of building types within the existing building sub-sector will allow for a feasible and positive financial method for the Municipality to achieve its climate targets.

However, further research is required to augment the methodology presented and make it useful in practice. A bottom-line cost-benefit analysis contributes to the spectrum of tools available to policy and decision-makers, however, economic growth has many complex mechanics that would have to be considered. Measuring the detrimental cost of extreme weather on human lives and infrastructure may provide a financial incentive to reduce the probability of a delayed response to climate change.

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Chapter 5: Conclusions and recommendations

5.1 Summary

"What we build today will be our emissions legacy, the buildings and construction sector needs to lock in new norms of energy efficiency, green materials, and better practice in design and construction." - Global Alliance for Buildings and Construction (GlobalABC, 2018).

The urgency to transition to a net-zero carbon economy has never been clearer, and the role of the built environment is being increasingly recognised as key to this transition. The vision is ambitious – to have all new buildings we live and work in to be net-zero carbon by 2030, and all buildings by 2050 (C40 Cities, 2019b). Businesses and governments around the world have identified that realising net-zero carbon buildings significantly improves reaching their emissions reductions target, as required by science (GlobalABC, 2018). This is due to the building sector, as an end-consumer of carbon emissions, accounts for around 30% of all GHGs globally.

With the sector growing rapidly due to population growth and increased levels of urbanisation, it is crucial to invest in a growing built environment that is low carbon rather than settle into high emitting buildings that will make any transition to a climate-safe future more complex. It is estimated that by 2050 the building sector will increase its floor area by 100%, with most of this growth occurring in Asia and Africa (WBCSD, 2018). It is however important to note that new buildings are only half of the problem. Especially in South Africa, existing buildings were largely not designed with energy efficiency in mind and will require deep retrofitting to attain the energy efficiency standards that could be achieved in the design of new buildings. It may also be more complex to allow for the installation of renewable energy due to the building's structural integrity and space limitations that may even apply to its dense surrounding areas.

The role of the building sector is vital, whether globally or in regard to the eThekwini Municipality's climate goals. The incorporation of the building sector is necessary when working towards the development of a climate strategy in any city or country. The research has identified various factors that differentiate the building sector from other sectors of the economy while highlighting that the potential for mitigation in the building sector is worth considering in plans to address and mitigate climate change. The drivers and trends behind these factors have been unpacked and it is undoubtedly clear that the building sector should be prioritised as a key action for the eThekwini Municipality in efforts of reducing GHG emissions. Further to this, it is noted that the developmental challenges faced by the eThekwini Municipality mean that any financial implications would need to be addressed, as decision-makers are required to substantiate investments. It has been documented that the building sector can provide the most amount of emissions reductions at the lowest cost in comparison to any other sector, and it became important to corroborate this research specific to the local context of the municipality.

This study, therefore, looked at high emitting sectors within the eThekwini Municipality to verify global findings that the building sector is indeed the sector to offer high abatement potential at the lowest cost, and then to offer an evidence-based pathway of implementation of climate actions.

This conclusion is based on findings from the thesis, where the following key objectives have been answered:

a) To evaluate the costs in achieving the abatement potential for each high-emitting sector in the eThekwini Municipality.

   Costs (ZAR) to reduce each ton of GHGs for individual interventions within high-emitting sectors in the eThekwini Municipality have been established and tabulated alongside the mitigation potential of each mitigation action. The objective of this research is to provide guidance towards the development of a strategy that would allow authorities to prioritise actions in addressing climate change within the building sector. Sectors covered in this assessment align with the approach used by the eThekwini Municipality, employing the GHG Protocol's BASIC level of reporting that excludes AFLOU and IPPU sectors. This study determined that the building sector is indeed the sector that offers the lowest cost to mitigate each ton of GHGs when compared to other sectors in the eThekwini Municipality. Several interventions within the building sector further display negative costs, meaning that the intervention will have a positive payback period throughout its lifecycle. The remaining sectors of waste, energy, and transport each have more than one intervention where the costs to reduce GHGs are listed individually.

b) To determine the sector that can offer the highest abatement potential at the least cost in the eThekwini Municipality.

   The main outcome of this research is that the building sector, out of all analysed economic sectors in the eThekwini Municipality, dominates the top 25th percentile of marginal abatement costs, which indicates that the building sector should be prioritised for early actions as it represents the most cost-effective sector to reducing the first 25% of the eThekwini Municipality's available lifetime mitigation potential. This cements a 2007 study conducted by the IPCC on a global scale and works effectively towards achieving the goals outlined by science in the Paris Agreement.

c) To develop and implement a tool to investigate the costs associated with implementing more granulated and specific interventions within sub-sectors of the building sector to determine which action offers the lowest cost pathway.

   With the understanding that the building sector should be prioritised as a key sector in reducing GHGs, the development of a focussed plan within the building sector is necessary for implementation. Within the building sector there exist subsectors of new buildings and existing buildings that have different dynamics to GHG reduction, in all building typologies. It is important in strategic planning to identify the actions required and the financial implication of each action, to facilitate the most appropriate investment into implementation. The aim of this research focussed on evaluating the life cycle cost differences of new and existing buildings for the first and most fundamental step to achieving a net-zero carbon building – energy efficiency. A cost model was developed to describe financial payback periods of various building typologies applying enhanced energy efficiency intervention. The model quantifies energy efficiency interventions per building typology and the subsequent financial value of each sub-sector's outputs. The Net-Zero Carbon Buildings Energy Efficiency Cost Comparison model is structured on the input of the cost of each energy efficiency intervention and then the projected lifetime savings of each intervention. In this way, the model can assist in the prioritization of climate change mitigation interventions within the building sector, based on financial feasibility.

A building would need to achieve the maximum efficiency gains before supplementing its remaining energy use with renewable energy to ensure that the system size of the selected renewable energy sources is optimal. Renewable energy can become a sizeable investment and energy efficiency will ensure against over expenditure on renewable energy, and a smaller renewable system would take up less space. Energy intensities contextualises the kWh consumption for every meter square of a building, allowing for a fair comparison of the various building typologies that can be a new or existing building.

Results from this study indicated that energy-efficient shopping centres and school blocks showed a positive financial case within the first year. Contrastingly, the business case for energy efficiency becomes less so in smaller convenience stores with the financial positive benefit not showing in the 15-year time frame but displaying in year 24. It is further interesting to note that energy-efficient low-rise office blocks showed a positive case from year 3 but that high-rise office blocks require 15 years of operation to become financially feasible. Commercial spaces less than 5000m² require 24 years to become financially feasible and all typologies within the residential sub-sector of buildings only become feasible after year 26.

d) To offer a suite of recommendations that would inform the pathway for implementation of climate actions in the eThekwini Municipality.

It is recommended that new buildings be prioritised for implementation before existing buildings, due to ease of implementation. Existing buildings are however necessary for inclusion into any strategies for emissions reductions, as these can still contribute to a significant proportion of the mitigation potential, at a cost that is comparable to new buildings. It is recommended that a phased approach be taken to address the different building typologies based on their financial outlooks. Buildings that display a financially positive bottom-line case should be targeted first, ensuring that there is adequate communication and marketing of the cost-benefit analyses associated with net-zero carbon buildings. This study concludes that new buildings should be prioritised in a phased approach, starting with building typologies that offer a positive financial payback first, and this include schools, shopping centres, and low-rise office parks. This should then be followed by the remaining sectors that includes the remainder of the commercial buildings, and the residential sector. The next phase of implementation should consider existing buildings in the same order as followed for new buildings.

As it is noted that both new and existing buildings are a vital part of the puzzle for achieving science-based GHG reductions, the prioritisation of building types within the existing building sub-sector will allow for a feasible and positive financial method for the Municipality to achieve its climate targets. It will be important to prepare the market in the understanding of net-zero carbon and its benefits, along with the implementation of a favourable regulatory environment for net-zero carbon building requirements.

5.2 Recommendations for future research

The research conducted in this study focused on gathering existing information relating to net-zero carbon buildings and quantified the bottom-line financial implications of decarbonising the building sector. Literature reviews and discussions thereof focused on definitions, concepts, characteristics, and descriptions of information relating to net-zero carbon buildings in the context of addressing climate change. This study aims to expand the knowledge base relating to net-zero buildings and their cost-benefit analysis. However, further research is required to augment the methodology presented and make it useful in practice.

The eThekwini Municipality employs the GHG protocol's BASIC level of reporting on the GHG report for the Municipal area. It is recommended that the Municipality improve its data collection processes to align with the BASIC + level of reporting that will include AFLOU and IPPU sectors. These sectors were omitted from this study to align with the standard used by the eThekwini Municipality and due to the data for the remaining sectors (AFLOU and IPPU) for the BASIC + approach being not available. While the complexity of this reporting method is noted, the BASIC + level of reporting is a more comprehensive and holistic approach to GHG reporting.

A bottom-line cost-benefit analysis contributes to the spectrum of tools available to policy and decision-makers, however, economic growth has many complex mechanics that would have to be considered. Ambitious climate change mitigation programmes, such as the transformation of the building sector, would impact employment levels. More jobs would be created via the creation of new job roles and businesses within the green economy. Further to the creation of jobs, there is significant potential of adverse impacts on municipalities' revenue - in particular revenues from electricity and utilities. The eThekwini Municipality would have to consider taking advantage of and creating new revenue generation opportunities to counter this. The reduction of GHGs will have positive externalities on the environment and health of residents which would have a follow-on effect of improved worker output via decreased rates of respiratory and immune-deficient conditions. A holistic cost-benefit analysis should also consider the opportunity costs and savings associated with tackling climate action and this may also include measuring the detrimental cost of extreme weather on human lives and infrastructure may provide a financial incentive to reduce the probability of a delayed response to climate change.

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