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REDUCING THE CARBON FOOTPRINT OF THE UNIVERSITY OF CAPE TOWN:
AN ENERGY SYSTEMS APPROACH

In partial fulfilment of the requirements for the degree of M.Sc. in Climate Change and Sustainable Development

Matthew Gabin (GBNMAT001)

Supervisor: Professor Harro von Blottnitz

Co-supervisor (s): Fadiel Ahjum (2021), Alison Hughes (2022)

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ABSTRACT

Universities are uniquely positioned to play a significant role in forging pathways to a sustainable future. As many of society's challenges are reflected in university systems, these can serve as useful testing grounds to inform interventions, such as emissions reduction strategies. As the University of Cape Town (UCT) has committed to several environmental sustainability goals, this dissertation investigates greenhouse gas emissions reduction pathways for UCT through an energy systems approach by constructing an energy systems simulation model to represent the institution's various proposed decarbonisation plans. The research built on UCT's series of carbon footprint reports and its proposed sustainability plans, focusing on electricity usage which required detailed data collection. This involved engaging with multiple stakeholders at different levels in order to construct an energy systems model on the LEAP (Long-range Energy Alternatives Platform) software. This dissertation specifically uses the LEAP model to conduct a scenario analysis on UCT's emissions reduction plans, while considering the drivers of the institution's energy demand.

This dissertation assesses three scenarios and their impacts with regards to UCT's Scope 2 emissions: Scenario 1 studies the impact of the national grid decarbonising, Scenario 2 the impact of on-site electricity generation from solar power and, Scenario 3 the impact of implementing energy-efficiency measures to reduce the institution's overall energy demand (where each scenario is built on its predecessor).

The results of the study found that the institution relies heavily on the national grid decarbonising to reach its sustainability commitments. Expected decarbonisation of the national grid could result in the institution's Scope 2 emissions being reduced by 7.5% by 2030 but accelerating thereafter for a reduction of 91.4% by 2050 (relative to 2019 emissions). In comparison, Scenario 2 would result in the institution's Scope 2 emissions being reduced by 15.1% by 2030 and growing to 97.6% by 2050 (relative to 2019 emissions). Finally, Scenario 3 would result in the institution's Scope 2 emissions being reduced by 24.5% by 2030, and by 97.9% by 2050 (relative to 2019 emissions).

This dissertation found that, with the current proposed decarbonisation scenarios, that UCT is able to significantly reduce its Scope 2 emissions, but the window for meaningful own action is short-term as much of the expected reduction post 2030 is from measures not implemented by the institution itself. A leading university should be

leading, and not lagging society. The insights from this study have demonstrated the impact of scenario analysis on informing emissions reduction planning and importantly, provide a strong foundation in the amalgamated data sets on which future modelling work can be built.

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ABBREVIATIONS

ANU	Australian National University
CO2	Carbon dioxide
CO2e	Carbon dioxide equivalent
EMC	Environmental Management Committee
EMP	Environmental Management Plan
ESRG	Energy Systems Research Group
ESS	Environmental Sustainability Strategy
GCPF	Green Campus Policy Framework
GHG	Greenhouse gas
GSB	Graduate School of Business
GULF	Global University Leaders Forum
HVAC	Heating, ventilation and cooling
IDF	Integrated Development Framework
ISCN	the International Sustainable Campus Charter
LCC	Life Cycle Cost
LEAP	Long-range Energy Alternatives Platform
P&S	Properties and Services
PV	Photovoltaic
REIPPPP	Renewable Energy Independent Power Producer Procurement Programme
SATIM	South African TIMES Energy Model

TD	Talloires Declaration
UCT	University of Cape Town

1 CHAPTER ONE: INTRODUCTION

Universities have consistently played a crucial role in dealing with global environmental issues, as their research outputs, curriculum and community engagements can create long-lasting environmental effects and societal change (Karatzoglou, 2013). Universities are capable of having both multiple and multiplier effects and impacts on society by demonstrating ‘best practice’ methods in their teaching, research and operations (Ralph & Stubbs, 2014). The critical factors that enable universities to tackle transformational changes necessary to immerse environmental sustainability into the university ecosystem include a pooling of multiple strategies, a well-built policy environment, and a motivation from leaders and environmental sustainability advocates (Ralph & Stubbs, 2014).

Although there are many facets to consider in transformational change in university ecosystems, the topic of energy transformations, and in particular electricity generation, is central in the conversation around driving environmental sustainability. Thus, universities cannot strategize transformational change without considering the importance of their energy supply and how this energy is being generated. To give this context, globally, over 40% of energy-related carbon dioxide (CO_2) emissions are due to the combustion of fossil fuels for electricity generation (Ritchie, Roser & Rosado, 2020). For decades, coal has been the main source for South Africa’s electricity generation – in 2019, coal produced 88% of the country’s electricity (Wright & Calitz, 2020; Hanto et al., 2022). Universities engaging with environmental sustainability should thus have to demonstrate ‘best practice’ transformational change by pursuing transformations and intervention strategies in their own energy supply.

Ambitious transformations in the energy sector will have to greatly consider the design and implementation of “net zero emissions systems”, which emit net CO_2 and potentially no greenhouse gases. The concept of net-zero emissions systems has gained momentum in recent years as countries and sub-national authorities set net zero goals. The design and assessment of these systems will contribute significantly to a strong policy environment that is able to drive sustainable change. Subjecting the design of these systems under various scenarios can provide insight into strategies that are best suited for reducing emissions, considering both cost and time of implementation as key factors of these strategies. Such insights can be utilized by organizational structures (whether that be government or at the management level of a university) to build robust policy that is able to drive these ambitious transformations in the energy sector.

The subject of this dissertation is the role that universities can embody and demonstrate when addressing the issues causing the climate crises, particularly those caused by the energy sector, and more specifically, how universities have the potential to act as testing grounds to drive transformative change in reducing their emissions. Thus, the resulting information produced from these testing grounds can be a useful tool in informing and assessing the viability of the policy and financing of these strategies implemented on larger scales – at the city, provincial or national level.

1.1 Background

Universities are uniquely positioned to play a significant role in forging pathways to a sustainable future. As their operations should not be motivated primarily by financial or political gain, they should be able to test novel systems and technologies that may promote creative solutions to global concerns in ways that corporations and governments are not able to do so (Aleixo, Azeiteiro & Leal, 2018). Universities have significant influence in shaping the mental models of society’s future, while also playing a significant role in societal transitions towards sustainable human development patterns (Horan et al., 2019). In fact, it can be argued that because universities are educators of future generations, they have an obligation to act more sustainably, and to act as leverage points in the broader societal transition towards sustainability (Aleixo, Azeiteiro & Leal, 2018; Horan et al., 2019).

From a global lens, the environmental impacts associated with universities are relatively small compared to other sectors, however, the difference is that the education sector views itself as playing a transformative role in global transformation (Derrick, 2013; Horan et al., 2019). This perspective allows for the experimentation and demonstration of sustainability solutions, as universities have been identified as the ideal testing ground for such solutions (Horan et al., 2019). Universities can be represented as ‘microcosms of society’ or miniature cities owing to their size, the diversity of its population and the many complex activities and operations that occur across their campuses - this includes their associated direct and indirect environmental impacts (Dyer & Dyer, 2017; Horan et al., 2019). Many of society’s challenges are reflected in university systems, thus they serve as useful testing grounds to inform carbon reduction strategies for growing populations in wider society (Horan et al., 2019).

There is an emerging body of literature around scenario development projects relating to decarbonisation of universities internationally. As one of the leading institutions on the African continent, UCT has somewhat belatedly only by 2019, claimed to play a leadership role by determining itself semi-quantitative greenhouse gas (GHG) emissions reduction targets for its own operations (UCT Environmental Sustainability Strategy, 2019). Since 1990, the institution has made both international and internal policy commitments to environmental sustainability including acceding to the Talloires Declaration (TD) in 1990, adopting the Green Campus Policy Framework (GCPF) in 2009, signing up to the International Sustainable Campus Charter – Global University Leaders Forum (ISCN-GULF) in 2012, releasing the UCT Environmental Sustainability Strategy (ESS) in 2019 and most recently the formation of the Khusela Ikamva Initiative in 2021.

The Energy Systems Research Group (ESRG) at UCT, which specialises in energy systems modelling, is one of five teams collaborating in the UCT Khusela Ikamva Campus Sustainability Project (2021-2025). Focused on the institutions' carbon footprint, it aims to harness UCT's rich knowledge towards building the evidence base and a socially robust approach for setting ambitious carbon footprint reduction goals, and to identify and initiate actions so that UCT can implement the required, most cost-effective measures.

This historical context demonstrates that UCT has aimed to be an institution that is committed to environmental sustainability, however, during the 3 decades since the inception of sustainable development as a global priority, transformations in its operations showed signs of being fragmented and sporadic. To give this commitment greater attention and consistency, the institution created a Directorate in the Office of the Vice Chancellor in 2018, and in April 2019, appointed a Director for Environmental Sustainability to lead this Directorate. The Director for Environmental Sustainability created the UCT ESS to expand on the institutions previous pledges and activities. The Environmental Sustainability Directorate within the Office of the Vice Chancellor was purposed to provide guidance and build momentum for the permanent integration of environmental sustainability in all spheres of the university. A well-functioning Environmental Sustainability Directorate would, in theory, allow for a phased approach for the implementation of sustainability measures, given resource and budget allocations, that grow over time. Part of the UCT ESS was to align UCT with local and global standards and trends, and hence the strategy focuses in particular in achieving ‘net-zero’ by 2050, where the term "net-zero" refers to attaining a total balance between emissions generated and emissions removed from the atmosphere (Fankhauser et al., 2021).

In pursuits of UCT achieving net-zero status, the institution would have to target interventions that reduce their Scope 1, Scope 2, and Scope 3 emissions. Scope 1 (direct and owned) covers emissions from sources that an organisation owns or controls directly. In other words, these are the emissions that are emitted into the atmosphere as a direct result of set activities at the firm level (Callahan et al., 2011). These are divided into four categories:

1) Stationary combustion (e.g., fuels or heating sources)
2) Mobile combustion, which refer to all vehicles that are owned or controlled by a firm (cars, buses etc.)
3) Fugitive emissions, which refer to leaks from greenhouse gases (e.g., refrigeration, air conditioning units etc.)
4) Process emissions, which refer to all emissions emitted from industrial processes and on-site manufacturing (e.g., CO_2 emissions from producing cement)

Scope 2 emissions (indirect and owned) are defined as the indirect emissions from the generation of purchased energy from a utility provider (Callahan et al., 2011). In other words, Scope 2 emissions are all greenhouse gas emissions released into the atmosphere through the consumption of purchased electricity, steam, heat and cooling. For the majority of corporations, electricity purchases would be the distinct source of Scope 2 emissions – in other words, it covers the electricity consumed by the end user.

Scope 3 emissions (indirect and not owned) are all indirect emissions that are not incorporated in Scope 2. Scope 3 emissions are all those emissions that produced from the value chain of the reporting organisation - incorporating both upstream and downstream emissions (Callahan et al., 2011). Upstream activities can include emissions from business travel, waste sent to landfill sites and wastewater treatment plants, whereas downstream activities can include emissions resulting from investments organisations make (Callahan et al., 2011). Figure 1-1 illustrates the definitions and provides examples of Scope 1, 2 and 3 emissions.

Figure 1-1: Defined scope emissions Credit: Plan A based on GHG protocol adapted from Callahan (2011)

In the context of UCT, the institution has been reporting its Scope 1 and Scope 2 emissions since 2012. Scope 2 emissions encompass the majority of the institution's emissions (excluding Scope 3 emissions) and has consistently been responsible for more the 95% of the University's total Scope 1 and Scope 2 emissions (UCT Carbon Footprint Report, 2019).

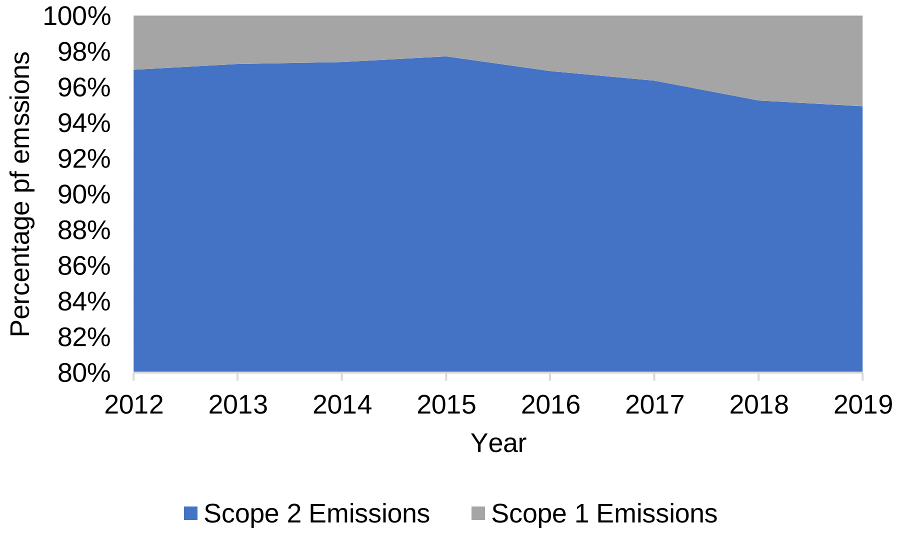

Figure 1-2: Percentage of UCT's Scope 1 and Scope 2 emissions, 2012-2019 adapted from the UCT Carbon Footprint Report (2019)

Many organisations share similar trends, in that their Scope 2 emissions greatly outweigh their Scope 1 emissions. In light of this perspective, the experimentation and demonstration of sustainability solutions at universities can provide useful insights to similar organisations that operate at a much larger scale (Horan et al., 2019). Thus, universities serve as useful testing grounds to inform carbon reduction strategies, particularly those involving Scope 2 emissions (Horan et al., 2019).

As UCT has made commitments though the UCT ESS in pursuing 'net-zero' by 2050, it is clear from Figure 1-2 that the institution would have to focus much of its efforts towards interventions involving Scope 2 emissions, and thus the institution would have to target its electricity consumption from both supply and demand side interventions.

1.2 Motivation of the study and problem statement

As universities can be viewed as 'microcosms of society', many of society's challenges are reflected in university systems, and thus they serve as useful testing grounds to inform carbon reduction strategies for growing populations in wider society (Horan et al., 2019). Like most universities, UCT has sustainability commitments, and regularly reports its carbon footprint. The institution has declared ambitious goals of achieving net-zero by 2050, and in viewing its historical emissions, it is clear that the institution needs to greatly target interventions relating to its Scope 2 emissions, which consequently refers to the way the institution sources and consumes its electricity.

In light of this, one must consider UCT's electricity supply and demand. On the supply side, UCT purchases all of its electricity from the national grid, where coal has provided the vast majority of South Africa's electricity and in 2019, coal was responsible for 88% of the country's generated electricity (Wright & Calitz, 2020; Hanto et al., 2022).

On the demand side, buildings are responsible for most of the institution's electricity demand. Thus, one must consider that UCT was originally founded in 1829, and that most of its buildings that exist today had been established post 1928 (UCT Integrated Development Framework, 2022). Given the age of most of its buildings, one must consider the operational efficiency, or rather inefficiencies, of many, if not most of its buildings.

Thus, in order for UCT to stay true to its commitments on achieving net zero by 2050, or at the very least to significantly reduce its emissions, the institution will have to focus its interventions on both the supply and demand side.

Although the university has outlined some of its emissions reduction plans on both the supply and demand side, there has not yet been a systematic analysis done to simulate these plans into pathways that would showcase how close the institution could get to achieving the stated net-zero emissions goal with its current proposed plans. This knowledge gap provides motivation for the study and is the core problem of interest.

1.3 Aims

This dissertation aims to provide insights as to whether UCT's current proposed plans for building energy efficiency retrofits and own power generation are sufficient to achieve its carbon footprint reduction commitments, or whether these plans fall short in achieving the stated net-zero goal. To achieve this aim, the dissertation reports on the building and use of an energy systems simulation model that can provide intelligence on setting emission reduction targets regarding UCT's Scope 2 emissions. The model maps UCT's electrical energy consumption and predicts its future demand based on the institution's expansion on the one hand, and demand reduction initiatives through energy efficiency investments and programmes on the other. On the supply side, different mitigation strategies are explored to lower the institution's carbon footprint by looking at the sourcing of renewable energy and scenarios where the university will generate its own electricity supply.

The study simulates various current proposed decarbonisation and sustainability plans into one model, to visualize how deep a reduction is possible with the current proposed plans, and their associated costs. The dissertation's main objectives are to:

1. Review the existing available data that characterizes energy consumption for campus wide services based on an extensive data collection process.
    - This involves reviewing building and facility typology and energy services; Heating, Ventilation and Cooling (HVAC), lighting, hot water supply etc.
2. Determine the data and data-structures required to construct a techno-economic energy-emissions model suitable for a campus level assessment.
    - This requires data decompositions of the energy services (e.g., investigating HVAC technologies and lifetime maintenance costs, lighting types and their retrofits, hot water supply technologies etc.)
3. Record the methods and assumptions used to build a techno-economic energy systems model for the UCT estate.
4. Present the model as calibrated to the published carbon footprint reports.
5. Present and analyse a reference case and two intervention cases for predicted energy use and associated Scope 2 emissions of the UCT estate until 2050.

6. Draw conclusions from this modelling and present recommendations for further model development and for management actions, stemming from this research.

1.4 Dissertation structure

The detailed structure of this dissertation is as follows: Chapter 2 presents the literature review of this dissertation. Section 2.1 begins with assessing how the higher education sector has been responding to the challenges sustainability presents. This section then elaborates on one such response strategy in particular, being the concept of a living lab, and details how its emergence has created an interface for universities to engage with external organisations, government and the local community. Further to defining the characteristics and types of living labs, this section continues to discuss UCT's projects that are considered living labs, and how this will inform the construction of the techno-economic simulation model. Section 2.2 presents the main sources of Scope 1 and Scope 2 emissions and elaborates on the types of operations that occur on universities that drive these types of emissions. It concludes with presenting the idea that universities must first understand their sources of emissions before being able to target and reduce them, where the use of evidence-based tools, such as energy systems models, can assist in this pursuit. Considering the understanding of a university's emissions to propose targeted reduction strategies, Section 2.3 presents UCT's historical carbon footprint from 2012-2019. It details the institution's electricity consumption, it's Scope 1 and Scope 2 emissions, and how these are calculated, reported, and influenced by the country's grid emissions factor. The idea of evidence-based tools/models being used to inform emissions reduction strategies were introduced in both Section 2.1 and Section 2.2. Thus, Section 2.4 elaborates on one such tool: the energy systems model. This section defines what an energy systems model is, its purpose and the different types of model classifications that exist. Furthermore, this section provides a high-level overview of the methodology used to construct a basic energy systems model, regardless of the software/platform being used. Finally, the literature review concludes with a review of smart energy systems in university campuses, captured in Section 2.5.

Chapter 3 presents the methodology of constructing the energy systems model used to simulate emissions reduction pathways for UCT's Scope 2 emissions. Section 3.1 outlines the research questions that this dissertation is aimed at answering, where Section 3.2 describes the energy systems modelling software, LEAP, and details how the construction of this model will aid in answering the research questions. Section 3.2.2 to 3.4 essentially describe the driving factors and mechanisms by which the simulation model is constructed. These sections detail the key drivers and assumptions of the simulation model, and then explores how the model will simulate UCT's electricity historical and projected demand. Additionally, this section outlines the projected energy transformations that feeds UCT's electricity supply. Section 3.3 explains how the energy systems simulation model is calibrated to fit UCT's electricity consumption as well as its unique energy profiles. The methodology chapter concludes with presenting the various emissions reduction scenarios, based on the proposed supply side and demand side interventions that are available to UCT.

Chapter 4 of this dissertation presents the key results and discussion points of this dissertation. It begins with presenting the qualitative results and learning points from interactions with various members of staff at UCT in Section 4.1. Section 4.2 reports the results of disaggregating the institution's electricity consumption profile into the various campuses, and then further into the type of buildings present on these campuses, and finally the disaggregation into the energy profile of said of buildings. Section 4.3 reports how accurately the model matches UCT's electricity consumption from 2012 to 2019, and projects its future demand based on the key assumptions listed in the methodology. Section 4.4 presents results of the first scenario, in which the national grid decarbonizes under an equivalent 2^{o}C warming scenario, while UCT continues to operate at current trends. The two intervention scenarios undertaken by UCT are presented in Section 4.5 (Scenario 2) and Section 4.6 (Scenario 3), which incorporate supply side and demand side interventions. Section 4.7 reports on the comparative analysis of these scenarios, by reporting which are the best performing interventions (in isolation and in combination) considering the 2030 and 2050 target timelines. The results of this dissertation conclude with an assessment of the implementation costs that are associated with the proposed supply side and demand side interventions, which are presented in Section 4.8.

Finally, Chapter 5 concludes this dissertation and summarizes the main conclusions and recommendations

2 CHAPTER TWO: LITERATURE REVIEW

This chapter reviews some of the relevant literature pertaining to the study. It starts with an overview of how universities can act as living labs for sustainable development. In the second section, the main sources of Scope 1 and Scope 2 emissions in the context of a university setting are explored. Thirdly, UCT's carbon footprint reporting (2012-2019) around Scope 1 and 2 emissions are presented, as well as the current strategies the institution has in place for improving sustainability. The fourth section of the literature reviews energy systems modelling and how it serves as a baseline for sound policy and investment. Finally, the literature explores prior modelling work of energy systems at similar scales.

2.1 Universities as living labs for sustainable development

The higher education sector has been addressing to the complexities sustainability presents in numerous ways, which includes the use of collaborative approaches and by executing campus assessments (Leal Filho, 2020). Much of this response is in reaction to the calls to help implement the sustainable development goals. In doing so, universities have been attending to the calls from its students for innovative, learner-centred approaches that integrate sustainable development in an interdisciplinary way for the purposes of deploying new and innovative learning methods, teaching concepts and didactic tools (Leal Filho, 2020). Globally, universities have been tackling the many challenges that are associated with implementing sustainable development through the development and deployment of specific "tools". One such tool that has emerged as an interface for universities to engage with external organisations, government and the local community is the concept of a "living lab", which aims to address a variety of challenges around implementing sustainable development while considering social challenges that may act as barriers to its deployment (Tercanli & Jongbloed, 2022). Living Labs are new types of innovation that are defined as user-centred, open innovation ecosystems that combine research and development processes in real-world communities and settings. Living Labs are techniques to change management, rapid service prototyping, co-creation, and other innovation management systems. They act as practice-driven institutions that incorporate real-life contexts where innovative processes may be researched, tested, and new solutions generated.

Living labs have drawn a lot of interest from academics because of the role that universities and their academic communities play in transmitting knowledge and innovation to society through outreach education programs for citizens. As a result, a living lab may be an effective teaching and action tool to encourage student involvement in community-based initiatives while bringing together stakeholders with various areas of expertise. Through this connection, the potential for expanding our understanding of sustainability is increased through this participatory research (Rosenberg Daneri, Trencher & Petersen, 2015; Purcell, Henriksen & Spengler, 2019; Leal Filho, 2020). Through the use of living laboratories, universities have the potential to turn into powerful forces for sustainability. This would validate the necessity for research studies with this focus in higher education settings where they are currently in place.

In a systematic literature review conducted by Tercanli & Jongbloed (2022), it was found that the highest number of university-governed living lab initiatives focused on issues present in the areas of urban sustainable development (Figure 2-1). This key finding reinforces the notion that Horan et al (2019) put forward - in that universities can be viewed as 'microcosms of society', and thus many of society's challenges, particularly those that are present in the urban space, are reflected in university systems, and thus they can serve as useful testing grounds to inform carbon reduction strategies for growing populations in wider society. In tackling the difficulties of urban sustainable development, universities and their infrastructures are frequently used as experimental and learning grounds, placing campus sustainability second in this list. (Figure 2-1).

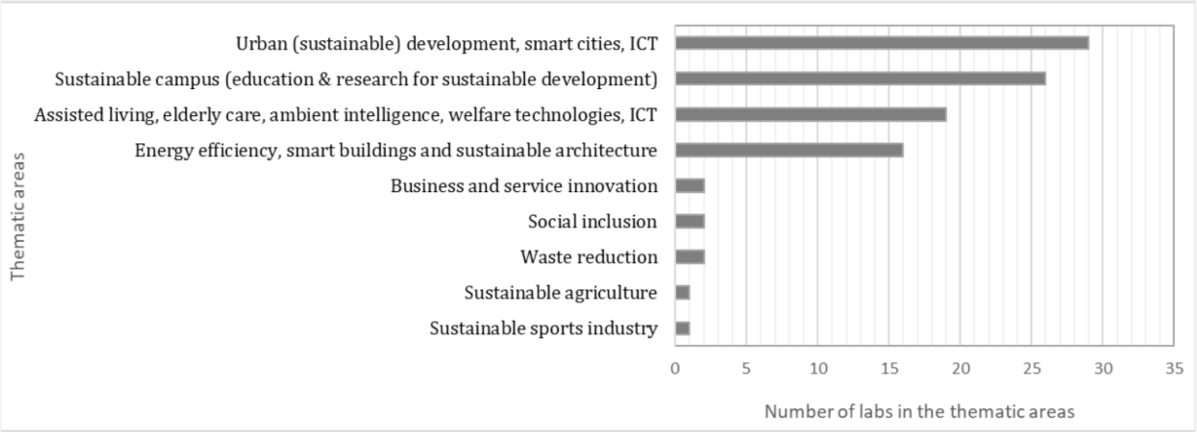

Figure 2-1: Challenges addressed and number of university-governed living labs in the thematic areas taken from Tercanli & Jongbloed (2022)

In the context of UCT, the institution has stated that its campus can “become a living laboratory for research on environmental sustainability while fulfilling its commitment to becoming a green campus.” The draft plan outlined in the UCT ESS (2019) has stated that this approach will cover five areas: governance, operations, learning, research, and stakeholder engagement.

Governance acts as underlying structure that ensures accountability for the implementation of living lab strategies. Operations refers to the running of the institutions buildings, water and energy consumption, as well as its waste management system. The learning aspect of this plan is to integrate a basic level of environmental sustainability into the curriculum of all students at UCT. Literature has confirmed that there is a strong link to research where the living laboratory is concerned, as research opportunities are able to be incorporated into campus facility projects (an example of this is this dissertation itself). Finally, UCT's campus facilities projects provide a plethora of research opportunities that should not be overlooked; hence, it is critical to establish relationships between the sustainability office and the various departments and research institutions in order to investigate such potential.

One project being launched at UCT (which could potentially act as a living lab), that is of great interest in this dissertation, is the UCT Solar Photovoltaic Project. In 2020, UCT had contracted Arup (Pty) Ltd to investigate the feasibility of the introduction of solar photovoltaic (PV) system installations at selected buildings across its campuses. Given the need to enforce environmental sustainability and the trend toward the utilization of renewable energy resources, UCT intended to reduce their carbon emissions and energy consumption by installing photovoltaic systems. The intention was aimed to reduce the demand and pressure UCT places on the utility grid, reduce annual operational costs and provide the means necessary to facilitate research work in addition to promoting renewable energy and environmental sustainability to the broader stakeholders of the university.

The demonstration of this project in this dissertation will highlight the effectiveness, or ineffectiveness, of universities as living labs and will be presented in the results section.

2.2 Sources of Scope 1 and Scope 2 emissions

As outlined by the Green Guide for Universities, the crucial first step in establishing sustainable campus operations is to first understand its environmental impact fully. In this understanding, emissions are classified in the following categories: Scope 1, Scope 2, and Scope 3. In the university context, Scope 1 emissions refer to the direct emissions from university related activities and Scope 2 emissions refer to indirect emissions from the generation of a purchased electricity, steam, heating, and cooling consumed by the university (UCT Carbon Footprint Report, 2019) .Universities have two main sources of emissions: emissions owing to the electricity consumption from their buildings (Scope 2) and their transport system (Scope 1).

2.2.1 Transport: Scope 1 emissions

Transport systems at universities contribute to the university's carbon footprint, with this only projected to grow with increasing populations (Green Guide for Universities, 2014). Universities offering sustainable modes of transport as the norm as opposed to an alternative act relies on behavioural pathways to decarbonisation, as it relies on behavioural change of the individual's choice (Green Guide for Universities, 2014). The Australian National University (ANU) demonstrates this through their Environmental Management Plan (EMP) which seeks to maximise sustainable transport and reduce emissions mainly through the university's carpooling programme and encouraging the use of the campus bike fleet, Australia's largest corporate bicycle fleet (Commonwealth of Australia, 2014).

As aforementioned, in the context of UCT, the institutions Scope 1 emissions have consistently contributed less than 5% of its combined Scope 1 and Scope 2 emissions, and hence will not be considered in this dissertation; rather, this dissertation will focus on the institutions Scope 2 emissions.

2.2.2 Buildings: Scope 2 emissions

According to the Green Guide for Universities (2014), the largest sources of CO_2 emissions in any given university is attributed to a building's energy use, whether electrical or thermal. On average, buildings are responsible for approximately 40% of total energy use, thus campus buildings offer one of the greatest opportunities for making universities more sustainable where many "low hanging fruits" could present themselves to lower the carbon footprint of the institution (Green Guide for

Universities, 2014). University building portfolios generally consist of a varied selection of old and new buildings, some of which are deemed “heritage buildings”, which make certain upgrades more complicated. On the other hand, retrofitting an existing building can be more cost-effective than constructing a new building, as there are more opportunities to retrofit a building’s lighting, water heating and HVAC (heating, ventilation and cooling) systems, all of which have shorter lifespans than the buildings themselves (Green Guide for Universities, 2014). Whether new buildings are being built or old ones are being renovated sustainably, significant planning is necessary to account for the whole life-cycle analysis on buildings - examining both the environmental effect and the economic worth of a building throughout its entire existence (from the extraction of resources to the buildings demolition and recycling).

Life Cycle Cost (LCC) analysis, an economic pathway to decarbonisation, is a tool for determining the economic costs and benefits of specific systems (Durairaj et al., 2002). LCC can be used to improve an operational feature of a building that is related to the design of the building (Durairaj et al., 2002). In addition to serving as an integral part of certain green certification schemes, it aims to identify the most cost-efficient strategies in a buildings design and construction, over the lifespan of the building. Pioneered and developed by ETH Zurich as a quality assurance tool for improving sustainability of its buildings, LCC is used by planners to make more economical and environmental decisions from the outset (Girmscheid, 2008).

Another opportunity that presents itself is using energy profiles of university buildings to identify and implement energy reduction opportunities and interventions (Maistry & Annegarn, 2016). As of 2022, UCT has employed two external consultancies to conduct energy audits on a sample of its buildings across its estate. In 2017, UCT contracted Terra Firma Solutions to conduct energy audits on 5 of its buildings, and in 2020, UCT had contracted SEM Solutions to conduct energy audits on an additional 16 of its buildings. These energy audits provided insight into the energy profile of the types of buildings at UCT, which identified opportunities to implement energy efficiency measures that would reduce the carbon footprint of the institution. These insights will be presented in the results section of this dissertation.

2.2.3 Strategies to decarbonisation

Universities typically approach decarbonisation from a governance perspective which aims to encompass technical pathways with economic pathways, often informed from an assessment of technologies in use versus potential reduction technologies. However, the power of universities exists in their ability to make education observable through evidence-based test models (Kourgiozou et al., 2021). One of these evidence-based models are energy systems models, which is explored in Section 2.4: Energy Systems Models.

2.3 UCT's Carbon Footprint

This section of the literature review explores UCT's Scope 1 and Scope 2 emissions, as well as the institutions policy commitments on sustainability.

2.3.1 Electricity grid emission factors

When reviewing UCT's Scope 2 emissions, which is from purchased electricity, the electricity grid emission factors that are provided yearly by Eskom must be taken into consideration, as this largely affects the values reported. These factors are the total amount of greenhouse gases emitted per unit of electricity generated for and distributed by an electricity grid (UCT Carbon Footprint Report, 2019). South Africa has a carbon intensive grid owing to the majority of its power generation being coal-fired. These emission factors should theoretically be decreasing overtime as renewable energy generation in South Africa increases (as per the national Renewable Energy Independent Power Producer Procurement Programme). However, the 2018 UCT Carbon Footprint Report showed that this emission factor had increased, with no transparent explanation given by Eskom.

In 2019, emissions as a result of electricity purchases at UCT accounted for 95% of the total of Scope 1 and 2 emissions (UCT Carbon Footprint Report, 2019), thus any changes in the grid emission factor greatly impact the institutions emissions results as they are based on the grid emission factor, as reported by Eskom (Table 2-1). This study recognizes that provincial and municipal governments do hold a level of decision-making power regarding the type of electricity generation occurring in their jurisdictions, opening the debate on how emissions factors could differ across provinces. However, this dissertation argues two points as to why the idea of varying emissions factors across provinces is counterproductive to this study. One, using the national electricity grid emissions factor standardizes the study and allows for consistency and comparison with past reporting on UCT's carbon footprint as these reports made use of the emissions factors as reported by Eskom. Secondly, one must look at the way in which electricity is generated and transmitted. Electricity is generated across the various power stations in South Africa and subsequently transported along power lines to the areas where it is needed. The national grid is the system of high-voltage power lines that connects the power plant to the urban, rural, and residential areas where electricity is used. All electricity that is generated is fed into this grid for national distribution. Furthermore, the electricity generated by power stations cannot be stored like water in a tank. It must be used as it is generated, thus computers in special control centres monitor how much electricity is needed throughout South Africa. Thus, the level of control exists within where electricity is needed, not what type of electricity is transported to a specific region. As electricity from renewable sources is also fed into the same national grid – there is no manual control to determine what type of electricity is fed where; it is all pooled together and transported as it is generated based on demand. The national grid emissions factor accounts for this. For the idea of a provincial emissions factor, there is no way to determine the exact proportion of the type of electricity being consumed, and one cannot assume this purely based off the type of power stations in that province as this generated electricity may be used in entirely different proportions based on demand in other provinces or geographical regions.

Table 2-1: Eskom electricity grid emission factors adapted from UCT Carbon Footprint Report (2018)

Eskom Integrated Report Year	Emissions factor (tonnes CO_2e/MWh)	UCT Carbon Report Year
2016	1.01	2015
2017	0.99	2016
2018	0.97	2017
2019	1.06	2018

2.3.2 Overall results: Scope 1 and 2 emissions

The total Scope 1 and 2 emissions increased by 8.1% from 69 536 tCO2e in 2017 to 75 186 tCO2e (Table 2-2) in 2018. During this period, the population grew by 0.9% (Table 2-4) with the gross UCT area remaining unchanged at 673 385 m^2. These emissions results are somewhat skewed owing to the 9% increase in the electricity grid emission factor reported by Eskom (Table 2-1). A more accurate picture is shown in the institution's electricity consumption, as this factor decreased by 2.2% in 2018 as compared to the 2017 year. Compared to the 2012 baseline year, while the population grew by 16.6% (Table 2-4), electricity consumption decreased by 1.7%, indicating that the universities sustainability measures have been improving.

Scope 1 emissions increased by 42.2% in 2018 as compared to 2017, largely due to the notably concerning increase in refrigerants, up 149% (Table 2-2). Vehicle fleet emissions decreased by 2.5% in 2018 as compared to 2017 – however in 2017 UCT renewed their bus fleet with higher specification buses, upgrading from European emissions standards Euro 3 to Euro 5 (UCT Carbon Footprint Report, 2019).

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Table 2-2: Comparative GHG emissions (tonnes CO_2e) for the period 2012-2019 adapted from UCT Carbon Footprint Report (2019)

CATEGORY	2012	2013	2014	2015	2016	2017	2018	2019
Scope 1: Direct emissions	**2 005**	**1 822**	**1 792**	**1 658**	**2 189**	**2 508**	**3 565**	**3 711**
Jammie Shuttle	1 076	1 068	1 006	861	790	902	769	1 025
UCT vehicle fleet	557	465	556	503	475	697	679	748
Liquefied petroleum gas (LPG)	372	289	230	160	191	102	105	95
Diesel for generators	NR	NR	NR	134	NR	NR	NR	50
Refrigerants	NR	NR	NR	NR	733	807	2 012	1 793
Scope 2: Indirect emissions purchased electricity	**64 619**	**65 835**	**67 446**	**71 569**	**68 504**	**67 028**	**71 621**	**69 706**
Electricity: Main Campus	42 394	42 583	44 219	46 933	43 774	44 001	47 024	44 512
Electricity: Medical Campus	11 044	10 648	11 239	12 027	11 654	11 477	12 993	12 238
Electricity: Off-campus residences	9 702	10 729	10 149	10 850	10 633	9 885	9 585	10 375
Electricity: GSB	1 363	1 417	1 393	1 387	1 382	327	301	839
Electricity: Hiddingh	116	116	111	-	527	504	622	602
Electricity: ICTS on Main	-	342	335	372	534	834	1 096	1 141
Total: Scope 1 & 2 Emissions	**66 624**	**67 657**	**69 238**	**73 227**	**70 693**	**69 536**	**75 186**	**73 417**

Table 2-3: Electricity consumption (kWh) for the period 2012-2019 adapted from UCT Carbon Footprint Report (2019)

	Year							
Location	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**
Main Campus	45 099 590	45 300 860	47 041 102	46 468 176	44 216 343	45 361 862	44 362 046	42 799 564
Medical Campus	11 748 434	11 327 625	11 956 697	11 907 690	11 772 167	11 831 500	12 257 939	11 767 126
Off-campus residences	10 321 043	11 413 739	10 786 078	10 742 859	10 740 748	10 191 196	9 042 415	9 975 606
GSB	1 449 791	1 507 070	1 481 849	1 373 429	1 396 321	337 287	284 413	807 006
Hiddingh	122 890	123 931	118 609	-	532 801	519 313	586 386	578 781
ICTS on Main	0	363 879	356 165	367 960	539 071	860 129	1 034 155	1 096 882
Total	**68 741 748**	**70 037 104**	**71 740 500**	**70 860 114**	**69 197 451**	**69 101 287**	**67 567 354**	**67 024 965**

Scope 2 emissions at UCT increased by 6.9% in 2018 as compared to 2017, largely due to the increase in the Eskom grid emission factor (UCT Carbon Footprint Report, 2019). In comparison, electricity consumption decreased by 2.2% (Table 2-3). Table 2-4 below summarizes key intensity metrics at UCT, which are useful for benchmarking the institutions performance both internally and against similar institutions.

Table 2-4: Key intensity metrics for the period 2012-2019 adapted from UCT Carbon Footprint Report (2018)

	Year							
	2012	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**
Tonnes CO_2e/m^2/annum	0.103	0.101	0.098	0.104	0.1	0.103	0.112	0.108
Population	30 579	31 041	31 329	33 204	34 965	35 343	35 673	35 745
CO_2e/person/annum	2.18	2.18	2.21	2.21	2.02	1.97	2.11	2.05
kWh/capita/annum	2 248	2 256	2 290	2 134	1 979	1 955	1 894	1 879

2.4 Energy systems models

2.4.1 Definition, purpose, and classification

Energy system models are defined as “techno-economic models that are able to guide decision-making on power capacity expansion” which is done by illustrating various strategies that are able to meet both future demands and environmental targets (Heuberger et al., 2017). Additionally, they are able to elucidate both the role and value of various technologies within the power system and stipulate optimal times of investment. Kondili (2010) describes energy systems models as mathematical models that aim to represent various possible energy-related problems as reliable as possible. Depending on the case in question, these models are able to express and address a variety of barriers - such as synthesis, design, operation and optimisation (Kondili, 2010).

Energy modelling provides insights into understanding current and future energy markets (supply, demand, and prices) and facilitates a more encompassing design of energy supply systems in short-, medium- and long-term timescales (Herbst et al., 2012; Rogner, 2017). It can be used to gain insight on how to ensure sustainable usage of energy resources, while understanding the present and future interactions of the energy market with the rest of the economy, as well as its potential impacts on environmental quality (Rogner, 2017). These purposes are useful for informing policy as well as optimal cost strategies around decarbonisation of a particular geographical and temporal scope. With the appropriate boundary conditions set, energy models can be utilized for the efficient forecasting, strategizing, design, operation, and optimisation of all energy systems (Kondili, 2010).

Energy systems aim to address the ‘energy-trilemma’, being energy security, economic competitiveness, and environmental consideration – components of which make energy systems modelling unique, and arguably superior, to other decarbonisation methods. Rogner (2017) simplified the classification of energy models, as displayed in Figure 2-2.

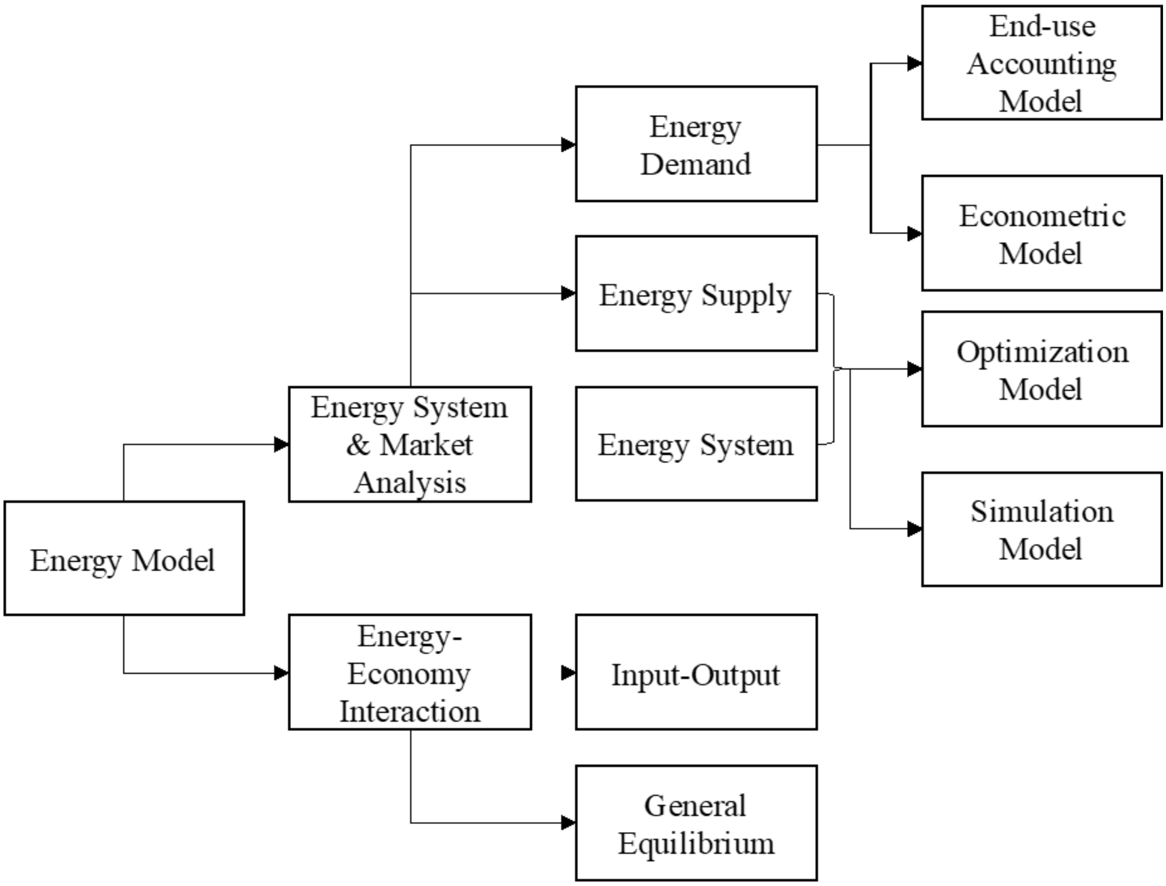


Figure 2-2: Simplified classification of energy models adapted from Rogner (2017)

2.4.2 Setting up an energy model

Rogner (2017) outlines three essential steps when setting up energy systems models, regardless of the type of energy model:

Step 1: Calibration of model to a base year

- Develop base year case, including all energy flows, balances, and trade flows
- In the base case, establish existing infrastructures and technologies which includes capacities and performance characteristics of the system (fixed and operating costs, lifetimes, load factors, conversion efficiencies/losses, emissions, fuel types etc.)
- Establish boundary conditions (constraints and restrictions)
- Finally, iterations are required with parameter adjustments until the model represents the base year reasonably well

Step 2: Determine new infrastructure, trade, and technology portfolio options

- This step involves factoring in existing technologies with future technologies, looking at capital costs (static and dynamic) as well as future fuel and import price developments
- Water, material and land requirements need to be established (direct and indirect)
- Examining market penetration constraints as well as financial and policy considerations

Step 3: Scenario development

- At this stage, considerations around demand projections, discount rates, energy security, access and environmental policy serve as some the variables that will inform different projection pathways

Heuberger et al (2017) outlines a similar framework, placing more emphasis on stakeholder involvement in the modelling process to produce results in usable forms to the main receivers of information.

2.5 A review of smart energy systems in university campuses

To date, scholarly literature has focused primarily on the role of energy system models in international and national energy policy-making, with empirical studies showing that models tend to hide the modellers’ subjectivity, which influences the shape policy may take (Ben-Amer et al., 2020). Energy models have been heavily criticized for insufficiently representing the complexities of society while addressing sustainability and energy transitions (Ben-Amer et al., 2020). Jefferson (2016) rejects the suitability of models depicting the complex world while Taylor et al (2014) argue that energy models both influence and are influenced by the social world, where the main value of an energy model lies in the underlying assumptions and contexts that serve to enrich the policy debate and not necessarily their outputs. Even with these criticisms, energy systems models remain prevalent in analyses of urban areas (Ben-Amer et al., 2020). Model development allows for the deeper comprehension of the energy system and its interconnected resources (both the physical and social) and aids in identifying knowledge gaps, which could be more valuable than the modelled results.

Ben-Amer et al (2020) selected three municipalities in Denmark (Copenhagen, Helsingør and Sønderborg) to depict the municipalities via a variety of different energy systems models and compared these to spreadsheet tools to assess the suitability and accuracy of each representation of the municipality. These three municipalities represent different types of communities within Denmark, as they differ greatly on total area, population (and expected growth) as well as emissions of CO_2/person. In comparison to global cities, Helsingør and Sønderborg are significantly smaller, hence their examination serves to address the underrepresentation of smaller urban centres in climate mitigation literature (Ben-Amer et al., 2020). In this study, the role of modelling tools in illustrating and facilitating an overview of the local energy system was highly noticeable in the case of Sønderborg, evidenced by the many stakeholder meetings and subsequent policy formation (Ben-Amer et al., 2020). Interviews with municipal stakeholders provided themed responses that the models were extremely useful for calculating the basis for strategies, roadmaps and for providing new measures for future planning. For example, Copenhagen was modelled through the energy systems model Balmorel, where these results were used to evaluate CO_2 emissions and the costs of district heating scenarios, which were then used as input for a different emission evaluation tool (CONNIE). This, in combination with overlapping municipal collaboration projects, were used to suggest alternative measures to improve the implementation of the city's Climate Plan (Ben-Amer et al., 2020). Similarly, modelling results from the LEAP platform were used as a background analysis for previous climate strategies proposed in Helsingør.

Ben-Amer et al (2020) was able to demonstrate that modelling of smaller scale urban centres is not only possible, but useful to municipal policymakers by providing insights on measures to decarbonize cities. The reported value of modelling the smaller urban centres, Helsingør and Sønderborg, is encouraging to apply the same techniques at the university level - Helsingør and Sønderborg have populations of approximately 63 000 and 75 000 respectively (Ben-Amer et al., 2020). In comparison, UCT has a current total population of 35 673 (UCT Carbon Footprint Report, 2018). Regardless, of this difference, energy systems models possess great potential in shaping policy frameworks for the decarbonisation of universities.

As universities act as microcosms of society and its challenges, energy systems models can potentially provide scalable pathways to net-zero carbon scenarios at a university level (Kourgiozou et al., 2021). However, there has been conflicting literature around scaling energy systems models to the level of universities. Ben Amer et al (2020) argued that planners at the municipal level prefer carbon calculators and spreadsheet tools over energy system models (mainly owing to the lack of understanding of models), while Horan et al (2019) demonstrated that how spreadsheet tools provide usable decarbonization roadmaps for university management at the university level. Using the University of Limerick as a case study, projections were conducted at a sectoral level and subsequently used to inform the individual profiles of various universities before being disaggregated down to individual campuses (Horan et al., 2019).

Although Kourgiozou et al (2021) do not explicitly use energy systems models in their scalable pathways to achieve net-zero in universities, the study strongly recommends the implementation of ‘Smart Energy Systems’, which refers to an integrated view that encompasses energy generation, management, transport, and consumption. Energy systems models can inform the smart energy systems concept; by balancing the supply and demand of energy over projected periods, energy systems models can lead to the improved implementation and utilization of renewables, lower emissions, and more efficient upgrades at building and campus levels (Cao, Dai & Liu, 2016).

2.6 Stakeholders using energy models to identify carbon-reduction target areas

As these energy models can be used to inform policy and institutional change, one has to consider the important role of the stakeholders that possess the power to physically implement this change. From students to university management, each actor has agency on what measures to pursue to reduce their institution’s carbon footprint. The energy systems model would be useful to some of these stakeholders to identify their prioritized target areas while considering the financial implication and implementation time of the targeted measures. The energy systems model will be able to illustrate the largest consumers of electricity by the university. As universities are largely an assembly of buildings, literature reports that the main electricity consuming groups in buildings are due to HVAC, lighting and equipment/computing systems. As these are significant contributors to carbon emissions in buildings, it is crucial to adopt targeted measures for carbon footprint reduction. The following discussion explores the opportunities, challenges, and efficacies of targeting HVAC, lighting systems, and equipment in buildings.

2.6.1 HVAC systems

HVAC systems offer substantial opportunities for carbon footprint reduction. Implementing energy-efficient HVAC technologies, such as variable speed drives, demand-controlled ventilation, and high-efficiency heat pumps, can lead to significant energy savings (Cao, Dai & Liu, 2016). Additionally, integrating renewable energy sources like solar thermal or geothermal for heating and cooling enhances the sustainability of HVAC systems (IEA, 2018).

However, one of the main challenges in optimizing HVAC systems is the high upfront cost of installing energy-efficient technologies. Building operators may be hesitant to invest without a clear understanding of the long-term benefits (Horan et al., 2019). Furthermore, retrofitting existing buildings poses technical challenges, requiring careful consideration of compatibility and space constraints.

Properly designed and maintained energy-efficient HVAC systems can result in substantial reductions in energy consumption and, consequently, carbon emissions (Horan et al., 2019). Studies have shown that implementing advanced control strategies and regularly maintaining HVAC systems can lead to energy savings of up to 40% (IEA, 2018).

2.6.2 Lighting Systems:

Upgrading lighting systems to energy-efficient technologies such as Light Emitting Diodes (LEDs) presents a significant opportunity for carbon footprint reduction. LEDs consume less energy, have longer lifespans, and can be integrated with smart lighting controls for optimized energy usage (Horan et al., 2019). Daylight harvesting systems further enhance energy savings by utilizing natural light when available.

The main challenge in adopting energy-efficient lighting systems is the initial cost of installation. However, the decreasing cost of LED technology and potential energy savings over time can offset these initial expenses (Horan et al., 2019). Additionally, addressing user preferences and ensuring proper lighting quality are essential considerations.

Transitioning to energy-efficient lighting systems, particularly LEDs, can result in substantial energy savings and a significant reduction in carbon emissions (IEA, 2020). Studies have shown that widespread adoption of LED lighting could contribute to a global reduction in electricity consumption for lighting by half (IEA, 2019).

2.6.3 Equipment in Buildings:

The equipment used in buildings, such as appliances and machinery, offers diverse opportunities for carbon footprint reduction. Choosing energy-efficient appliances, implementing advanced energy management systems, and adopting circular economy principles in equipment manufacturing contribute to a more sustainable built environment (IEA, 2019).

The challenge lies in the diversity of equipment types and their varying energy profiles. Establishing standardized energy efficiency measures for different types of equipment can be complex, and ensuring compliance requires effective regulations and monitoring (IEA, 2021). Additionally, user behavior and preferences play a role in equipment efficiency.

Efforts to improve the efficiency of equipment in buildings can lead to substantial energy savings and reduced carbon emissions. Regulatory initiatives, such as energy efficiency standards for appliances, have demonstrated success in driving the adoption of more sustainable equipment (IEA, 2022).

Targeted measures focusing on HVAC systems, lighting, and equipment in buildings present significant opportunities for reducing the carbon footprint of universities. While challenges such as upfront costs and diverse equipment types exist, the efficacies of these measures, when implemented thoughtfully, are supported by a growing body of research and successful case studies. Energy systems models would be useful to the stakeholder to identify the largest consumers of electricity, and in which specific area of the university this occurs (e.g. data centers at universities are expected to have a high electricity consumption due to the equipment being operated and the cooling systems required to maintain their functionality and similarly, older buildings of the university may consume more electricity due to inefficient lighting). This information is useful to the stakeholder in deciding the level priority that these measures can be targeted.

2.7 Conclusions from the literature review

Although aiming to be a university that is committed to environmental sustainability, transformations in UCT’s operations have been ad-hoc and not entirely aligned with the institution’s statements. The presented literature on UCT’s historical carbon footprint provides insight into the institution’s source of emissions and which type of emissions reduction strategies the institution should focus on in order to significantly reduce its emissions. In assessing this, Scope 1 emissions in 2019 were reported at 3 711 tons/CO_2e – in comparison, the institution's Scope 2 emissions were reported at 69 706 tons/CO_2e in the same year (UCT Carbon Footprint Report, 2019). In fact, UCT's Scope 2 emissions have consistently accounted for more than 95% of its total Scope 1 and Scope 2 emissions since the institution started reporting its carbon footprint in 2012 (UCT Carbon Footprint Report, 2019). In light of the institution declaring its ambitious commitments to achieving net-zero by 2050, its emissions reduction plans would need to largely target its Scope 2 emissions, as these account for a majority of its reported combined Scope 1 and Scope 2 emissions. Scope 2 emissions in the context of UCT are a result of the institution purchasing electricity for its operations, namely for the operation of its buildings. Based on the literature, there are two factors to consider when planning emissions reduction strategies around electricity consumption in buildings: the fuel types used in electricity generation and the level of energy efficiency technologies present in these buildings. This indicates that emissions reduction strategies have to target both the supply and demand side: this is especially important as the institution sources its electricity from the national grid which is heavily fossil fuel based, and given the age of most of its buildings, one must consider the level of operational energy efficiency.

An emerging theme in campus sustainability is the idea that universities can operate as living labs for sustainable development. Literature agrees that living labs are practice-driven institutions that incorporate real-life contexts or settings where both open innovation and user innovation processes may be researched, tested, and new solutions generated. UCT has employed the use of its own living lab plan that is outlined in the UCT ESS (2019) aiming to cover five key areas: governance, operations, learning, research, and stakeholder engagement. Based on this dissertation focusing largely on UCT's operations in order to reduce the institution's carbon footprint, the operations aspect of UCT's living lab draft plan (the installation of solar photovoltaic system across its campuses) is of great interest in incorporating this into its supply side emissions reduction strategy.

Finally, the literature has reported that in order for an institution like UCT to reduce its carbon footprint, it would require the use of a well-planned strategy. The literature has presented a viewpoint by arguing for the use of smart energy systems models for informing emissions reduction strategies. In the case study of Ben-Amer et al. (2020), energy systems models were highly capable of modelling smaller scale urban centres and were able to provide insights on measures to decarbonize these urban centres to municipal policymakers. The case studies of modelling smaller urban centres is encouraging to apply the same techniques at the university level. Thus, this dissertation proceeds on the premise that energy systems models can add value in shaping policy frameworks for the decarbonisation of universities (Kourgiozou et al., 2021).

3 CHAPTER THREE: METHODOLOGY

This section of the dissertation details the methodology used in the process of constructing the energy systems model that would be used to determine the level of emissions reduction UCT can achieve, given its current sustainability plans.

3.1 Research Questions

As stated in Chapter 1, the study aims to provide insights as to whether UCT's current proposed plans for building energy efficiency retrofits and own power generation are sufficient to achieve its carbon footprint reduction commitments, or whether these plans fall short in achieving the stated net-zero goal. The development of a techno-economic energy systems model that maps UCT's electricity demand and supply is proposed to generate and visualize these proposed reduction pathways, so as to provide intelligence on setting emission reduction targets regarding UCT's Scope 2 emissions. In doing so, the dissertation aims to answer the following research questions:

1. In understanding UCT's energy profiles and consumption data, what is a suitable level of disaggregation of energy data that can provide decision makers new insights?
2. What insights are gained through engaging with various stakeholder, and are transferrable in the case of constructing an energy systems model to inform policy around decarbonising the university?
3. How useful are energy systems models in providing insights into emissions reduction strategies and with the institution's current plans, which of the type of interventions (supply side vs demand side) have a greater impact on reducing UCT's carbon footprint?
4. How accurately is the LEAP model able to simulate UCT's historical emissions?
5. What are the associated implementation costs of these emissions' reduction strategies?

3.2 Leap Model Methodology

Figure 3-1 presents the outline of the methodology that was used to conduct this dissertation, to construct the energy systems model, and to aid in answering the research questions.

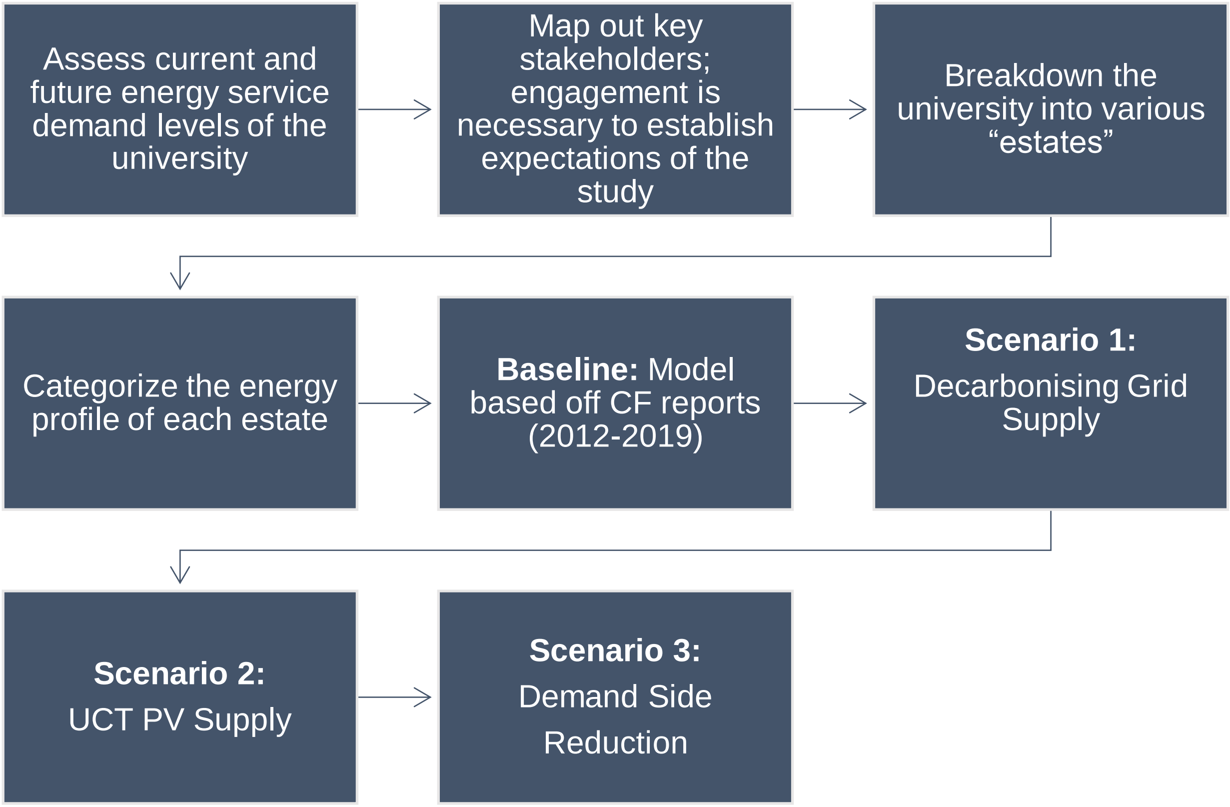


Figure 3-1: Schematic of overall methodology

The literature has reported that in order for an institution like UCT to reduce its carbon footprint, it would require the use of a well-planned strategy. The literature review has presented a viewpoint by arguing for the use of smart energy systems models for informing emissions reduction strategies. The case studies mentioned in Ben-Amer et al. (2020) demonstrate that energy systems models were highly capable of modelling smaller scale urban centres and were able to provide insights on measures to decarbonize these urban centres to municipal policymakers. These case studies of modelling smaller urban centres demonstrate the potential to apply the same techniques at the university level. Energy systems models are useful for comparing different investment options available to achieve a desired set of goals (Rogner, 2017). Thus, the goal of the study is how to best meet UCT's energy needs while minimizing both costs and emissions. One such tool that is capable of executing this is through LEAP software, which is a scenario-based energy-environment modelling tool (Stockholm Environment Institute, 2005). LEAP can consider scenarios that are based on the comprehensive accounting of how energy is produced, converted, and consumed in a specific region under a range of key assumptions, including area, population, technology and cost. As mentioned in the literature review, the power of energy systems models lies in guiding decision makers on power capacity expansion by illustrating different strategies to meet both future energy demands and environmental goals (Heuberger et al., 2017). The benefit of using LEAP exists in its flexible data structures and ease of use. This allows decision makers to move policy ideas into policy analysis without the need for more complex models (Stockholm Environment Institute, 2005). LEAP serves multiple purposes: as a database, it is able to provide detailed energy information systems; as a forecasting tool, LEAP enables the user to build projection scenarios of both energy supply and demand over a given time period; and finally, as a policy analysis tool, LEAP simulates and assesses the physical, economic and environmental effects associated with each scenario (Stockholm Environment Institute, 2005). LEAP is able to project energy supply and demand scenarios in order to provide insight into future energy patterns, identify potential problems and shortcomings, and assess the potential impacts of energy policies (Stockholm Environment Institute, 2005). This information is useful to stakeholders as it allows them to prioritize their targeted measures for demand side carbon reduction (importantly in Step 2 of Figure 3-1, where these measures can be compared to target actions as mentioned in literature – see section 2.6 Stakeholders using energy models to identify carbon-reduction target areas).

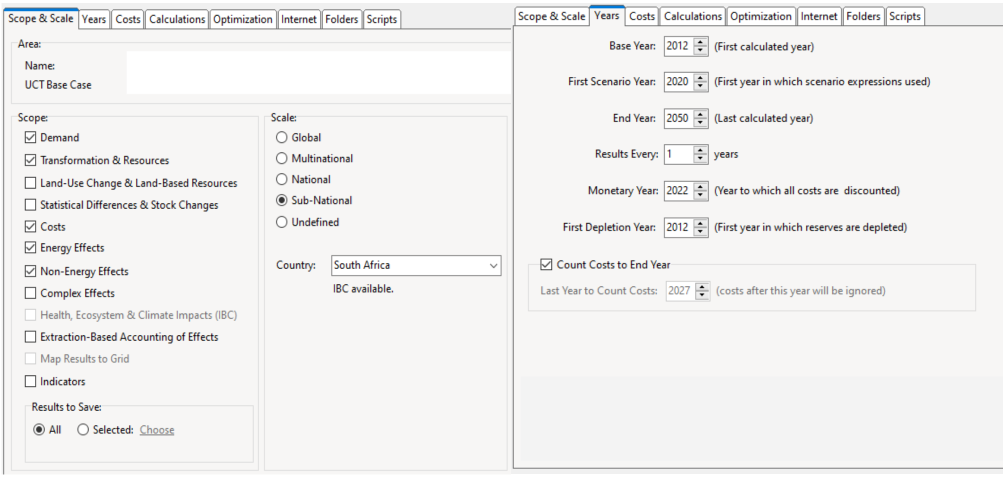
The LEAP analysis was conducted in the following steps:

1. Assess the current and future electrical energy service demand levels of the university
2. Map out key stakeholders/decision makers that would use the model and its results; engagement is necessary to establish expectations of the study
3. Assess how these services are currently being met, including:
    a. The fuel type of these services

    b. The remaining lifespans of these services
4. Review secondary factors affecting energy consumption and/or possible building improvements
5. Assess what types of appliances or technologies are available for meeting future energy needs to replace and/or upgrade existing appliances or technologies
6. Review supply options:
    a. For electricity, this includes projected grid tariffs and emission factors over the timespan the model will cover, as well as an evaluation of resource potential offered for rooftop self-generation and associated costs (including generating patterns)
7. Assemble this collected data into a LEAP model which describes the university campus in the following ways:
    a. How energy services are currently being met
    b. The projected service demands of the university – with key assumptions around area and population expansion
    c. Various options/technologies for meeting these energy service demands that allow the ‘energy system’ to reduce the emissions of the university
    d. The resultant energy use and associated emissions
8. Develop simulations from the ‘base case’, by adding a series of scenarios to determine and illustrate the pathways for meeting the emission reduction targets.

3.2.1 The LEAP Interface

In order to set up the model, certain settings need to be selected, as this will allow for further scenario development. The ‘scope and scale’ of the model as well as its key time variables are shown in Figure 3-2 below:



Area:
Name:
UCT Base Case

Scope:
☑ Demand
☑ Transformation & Resources
☐ Land-Use Change & Land-Based Resources
☐ Statistical Differences & Stock Changes
☑ Costs
☑ Energy Effects
☑ Non-Energy Effects
☐ Complex Effects
☐ Health, Ecosystem & Climate Impacts (IBC)
☐ Extraction-Based Accounting of Effects
☐ Map Results to Grid
☐ Indicators

Results to Save:
● All ○ Selected: Choose

Scale:
○ Global
○ Multinational
○ National
● Sub-National
○ Undefined

Country: South Africa
IBC available.

Base Year: 2012 (First calculated year)
First Scenario Year: 2020 (First year in which scenario expressions used)
End Year: 2050 (Last calculated year)
Results Every: 1 years
Monetary Year: 2022 (Year to which all costs are discounted)
First Depletion Year: 2012 (First year in which reserves are depleted)
☑ Count Costs to End Year
Last Year to Count Costs: 2027 (costs after this year will be ignored)

Figure 3-2: Selected settings in LEAP for UCT Base Case

Information on UCT's energy supply, demand and carbon footprint began reporting in 2012, hence this was selected as the model's base year. At the time of assessment, the most recent data made available was that found in UCT's 2019 Carbon Footprint Report, hence the first scenario year selected was 2020. Two key timelines were selected in line with those of the Sustainable Development Goals, being 2030 and 2050 respectively – thus 2050 served as the end year of the model simulation.

Once these were selected, the next step was to construct the interface of the model. LEAP is built off an interface of 'trees' – a hierarchical outline used to organize and edit the main data structures in the LEAP analysis. Data in the tree are organized under four major categories:

1) Key Drivers and Assumptions
2) Demand
3) Transformation
4) Resources

3.2.2 Key Drivers and Assumptions

The key drivers and assumptions category in the LEAP model are where independent variables are created and organized that are used to "drive" the calculations in you're the Demand, Transformation and Resource categories. Although these are not directly calculated in LEAP, they serve as useful intermediate variables that can be referenced in the models' calculations. Based off UCT's intensity metrics outlined in Table 2-4, UCT's building floor area was taken as the influential factor for energy demand. Historically at UCT, an increase in area has resulted in an increase in energy demand (important to note that this area expansion is driven by an underlying increase in population, however the relationship between area and energy demand is not linear owing to buildings become increasingly more efficient - a scenario considered at a later stage of this model).

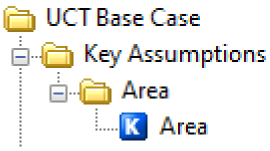


Figure 3-3: Key assumptions for UCT's base case

Figure 3-3 above illustrates the ‘Key Drivers and Assumptions’ category in the LEAP interface tree. As previously mentioned, building floor area was taken as the key driver for energy demand with 2012 selected as the base year, thus any future expansion of the UCT estate would be in reference to the 2012 base year. Table 3-1 below reports the historical total area of UCT in 2012, 2018 and 2019 (UCT Carbon Footprint Report, 2019).

Table 3-1: Projected area expansion of the UCT estate

Year	2012	2018	2019	2030	2050
UCT Total Area (m^2)	649 404	673 385	677 385	727 985	778 585
% Increase		3.69%	4.31%	12.10%	19.89%

Based on UCT’s Integrated Development Framework, the approximate additional space requirements for the University would be an additional 50 600 m^2 of academic floor area by 2030 (which correlates to a 12.1% increase in floor area from a 2012 baseline). Based on this trajectory, it was assumed that an additional 50 600 m^2 would be required by the year 2050 to meet the needs of the UCT population (correlating to a 19.89% increase in area based off a 2012 baseline). These percentage increases in UCT’s area were incorporated into the model’s key assumptions, shown in Figure 3-3.

3.2.3 Demand

The second step in model sequencing is to determine the ‘Demand’ branch – the category under which the disaggregated structure of the energy demand analysis is created. Demand analysis is an end use-based approach for modelling the requirements for the final energy consumption in a given area. Energy demand analysis serves as the initial starting point for conducting integrated energy analysis, as all Transformation and Resource calculations are driven by the levels of the final demand calculated in the demand analysis.

In the case of UCT, the demand sectors were based on UCT's distinctive campuses, which can be shown in Figure 3-4. The UCT estate was broken down into eight distinctive campuses, and further categorized into Academic type buildings and Residence type buildings (the reason being that their energy profiles differ). The energy profiles of each of these respective types of buildings were deduced from the energy audit reports conducted by SEM Solutions, which will be discussed in further detail under 3.3 Calibration of UCT's Electricity Consumption and Energy Profile.

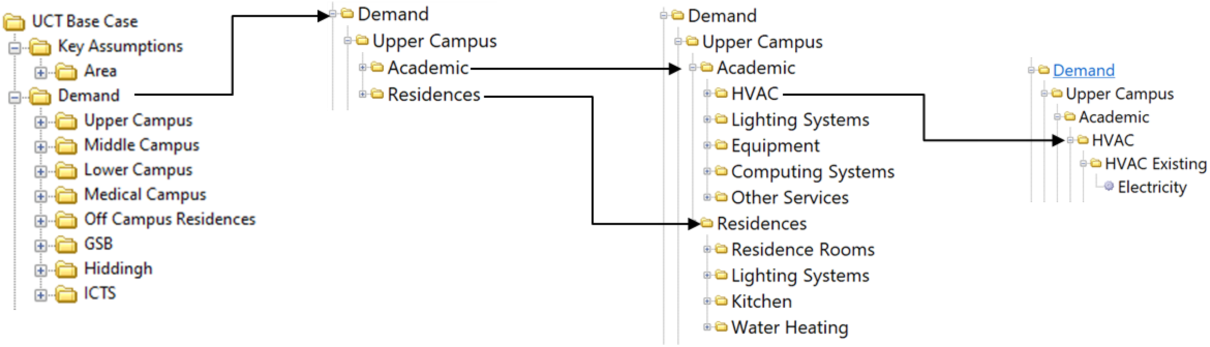
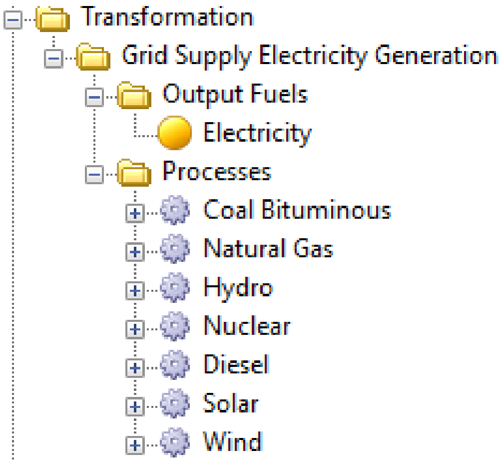


Figure 3-4: Disaggregated structure of the UCT Estate

After being further disaggregated into energy profiles, the underlying energy source type was specified. In this case, electricity is the underlying energy source type for all UCT's campuses.

3.2.4 Transformation

The third step in model sequencing is to create a 'transformation analysis' that simulates the conversion and transportation of energy forms from the point of extraction of primary resources and imported fuels to the final point of fuel consumption. In the base case, data was obtained from the Energy Systems Research Group (ESRG) at UCT to replicate South Africa's grid supply matrix. Essentially, this data represents how the grid supply matrix should "decarbonize" by 2050 under various scenarios, which can be found in found in Appendix B1: Scenario 1 – Decarbonization of the National Grid under Table 7-11. The grid supply matrix that was chosen corresponds to a 2^{o}C warming by 2050. The fuel types that serve as a source for grid-supplied electricity are shown in Figure 3-5.



Transformation
  Grid Supply Electricity Generation
    Output Fuels
      Electricity
    Processes
      Coal Bituminous
      Natural Gas
      Hydro
      Nuclear
      Diesel
      Solar
      Wind

Figure 3-5: Fuel source types for Transformation Analysis

For each of these fuel source types that contribute to the electricity generation, process efficiencies were sourced and are reported in Table 3-2 below :

Table 3-2: Process efficiencies for grid supply fuel types (Department of Mineral Resources and Energy, 2019)

Fuel Type	Process Efficiency
Coal Bituminous	35.5%
Natural Gas	42%
Hydro	90%
Nuclear	32%
Diesel	30%
Solar	29.3%
Wind	36.2%

For consistency purposes, these process efficiencies were kept constant throughout the scenario analysis from the 2012 base year until the projected 2050 target.

3.2.5 Resource

The Resource Analysis in LEAP is used to encapsulate data on the availability of the primary resources that are consumed in the Transformation Analysis. It specifically allows the user to provide boundaries for each resource – boundaries can range from cost-benefit analysis to the total available resource reserves. In this assessment, there were no resource boundaries placed on the fuel types, as the decarbonisation of the

Eskom grid supply is an independent process of UCT's efforts towards reducing its own carbon footprint. However, although this is an independent process, the downstream effects of this are beneficial for UCT as the institution purchases electricity from the City of Cape Town, who in turn sources this from Eskom – purchases of cleaner electricity result in a reduced attributed carbon footprint.

3.3 Calibration of UCT's Electricity Consumption and Energy Profile

This section details how the energy profile for each UCT campus was configured in the LEAP model, based off final energy consumption reported in the 2019 Carbon Footprint Report and the Energy Audit Reports conducted by a contracted specialist, SEM Solutions, for the University.

3.3.1 Disaggregation of Main Campus

The 2019 UCT Carbon Footprint report documents historical annual energy consumption from 2012 to 2019 for the Main Campus, Medical Campus, Off Campus Residences, the Graduate School of Business (GSB) Campus, Hiddingh Campus and ICTS on Main. However, for the purposes of this model, main campus was disaggregated into the individual Upper, Middle and Lower Campuses. This was based on building floor areas, and it was assumed that the ratio in areas between the three campuses would be the equivalent ratio in energy consumption between the three campuses. Appendix A: Campus Area's and Energy Profiles indicates the total areas for Upper, Middle and Lower Campus based on the total number of buildings present on each campus. Table 3-3 below summarizes this data and indicates the ratioed area between Upper, Middle and Lower Campus. Additionally, Table 3-3 applies this ratio to the 2019 total energy consumption of Main Campus in order to estimate the individual energy consumptions of the disaggregated campuses.

Table 3-3: Summarized areas and energy consumptions of Upper, Middle and Lower Campus in 2019

Location	Area (m^2)	% of Main Campus	Energy Consumption (kWh)
Main Campus	**418 924**		**42 799 564**
Upper Campus	281 352	67%	28 744 483
Middle Campus	56 986	14%	5 822 047
Lower Campus	80 585	19%	8 233 034

3.3.2 Disaggregation of each campus into Academic vs Residence type buildings

Once the eight UCT campuses were established, they were further disaggregated into Academic type buildings and Residence type buildings, as these types have significantly different energy profiles. The areas of these buildings were used to determine the split between academic type buildings and residence type buildings. Similar to the disaggregation of the Main Campus into Upper, Middle and Lower Campus based on an area ratio, it was assumed that the ratio in area of academic vs residence type buildings would equate to the ratio in total energy consumption of that particular campus. The reasoning behind this is that underlying meter data was not made available at the time of the study, and hence assuming that area ratios equated to total energy consumption ratios was the next best option to profile the institutions energy use. This is demonstrated using Upper Campus as an example:

$$Total\ Area\ of\ Upper\ Campus = 225\ 257\ m^2$$
$$Total\ Area\ of\ Academic\ Type\ Buildings = 208\ 866\ m^2$$
$$Total\ Area\ of\ Residence\ Type\ Buildings = 16\ 391\ m^2$$

Appendix A1: Upper Campus

Using this data, the ratioed areas for Upper Campus are calculated in Equation 1 and Equation 2 below:

$$\%\ \text{of Academic Type Buildings} = \frac{\text{Total Area of Academic Type Buildings}}{\text{Total Area of Upper Campus}} x\ 100$$

Equation 1

$$= \frac{208\ 866\ \text{m}^2}{225\ 257\ \text{m}^2} x\ 100$$

$$= 92.72\%$$

$$\%\ \text{of Residence Type Buildings} = \frac{\text{Total Area of Residence Type Buildings}}{\text{Total Area of Upper Campus}} x\ 100$$

Equation 2

$$= \frac{16\ 391\ \text{m}^2}{225\ 257\ \text{m}^2}$$

$$= 7.28\%$$

With this assumption, it is estimated that 92.72% of the total energy consumption of Upper Campus is from Academic type buildings, while 7.28% of the total energy consumption of Upper Campus is from Residence type buildings. The same methodology was applied to the remaining campuses that possessed both academic type buildings and residence type buildings (Middle Campus, Lower Campus, and Medical Campus) while the remining campuses of ICTS on Main, GSB and Hiddingh were all assumed to only possess academic type buildings, while the Off Campus Residences were assumed to possess only residence type buildings.

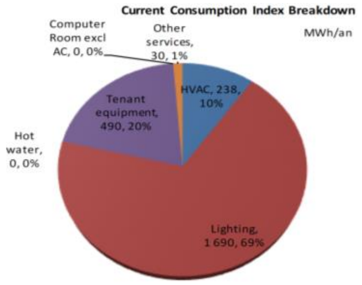
A key assumption in this is that 2019 areas were used to calculate these ratios across each individual campus, and this ratio was kept constant throughout the timeline of the model (i.e. these ratios were kept constant from 2012 until 2050).

3.3.3 Disaggregation of Building Types into distinct Energy profiles

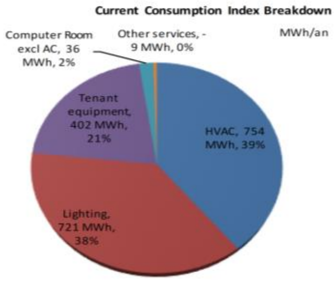
The final stage of disaggregation in the model sequencing was to establish unique energy profiles for each individual building type. To demonstrate this, the Academic Building types in Upper Campus will be used as an example.

SEM solutions conducted 16 energy audit reports that were spread across different buildings on various UCT campuses. In their audits, they were able to estimate the energy profiles of these assessed buildings. Figure 3-6 showcases the buildings that were assessed on Upper Campus along with their associated energy profiles determined by SEM Solutions.

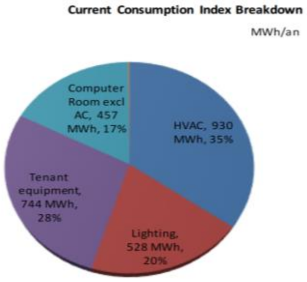
Leslie Commerce



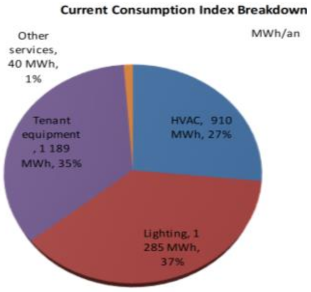
GH Menzies



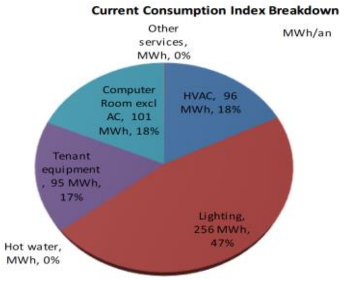
Snape



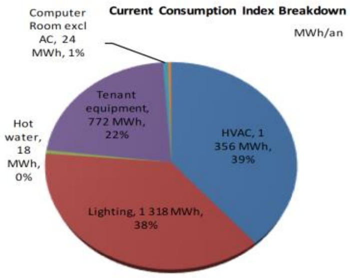
PD Hahn



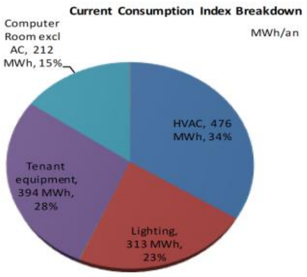
RW James



Molecular Cell Biology



John Day



Robert Leslie Social Sciences

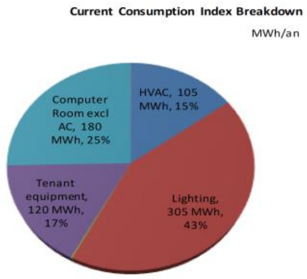


Figure 3-6: Energy Profiles from energy audits conducted by SEM Solutions of buildings on Upper Campus

In total, eight academic buildings on upper campus were assessed (Figure 3-6). These results were assumed to be a fair sample to represent all academic type buildings on upper campus. Table 3-4 summarizes the data of the eight energy audit reports of buildings on Upper Campus. Using these energy profiles, the energy profile of the entire upper campus was estimated. To determine the energy profile of Upper Campus, the following set of equations were used based on the summarized data in Table 3-4.

$$\%\ \mathrm{HVAC} = \frac{\sum \text{Energy consumption of HVAC of the sample size}}{\sum \text{Total energy consumption of sample size}}\ \mathrm{x}\ 100 \qquad \text{Equation 3}$$

$$\%\ \text{Lighting Systems (LS)} = \frac{\sum \text{Energy consumption of LS of the sample size}}{\sum \text{Total energy consumption of sample size}}\ \mathrm{x}\ 100 \qquad \text{Equation 4}$$

$$\%\ \text{Equipment} = \frac{\sum \text{Energy consumption of Equipment of the sample size}}{\sum \text{Total energy consumption of sample size}}\ \mathrm{x}\ 100 \qquad \text{Equation 5}$$

$$\%\ \text{Computing Systems (CS)} = \frac{\sum \text{Energy consumption of CS of the sample size}}{\sum \text{Total energy consumption of sample size}}\ \mathrm{x}\ 100 \qquad \text{Equation 6}$$

$$\%\ \text{Other} = \frac{\sum \text{Energy consumption of Other of the sample size}}{\sum \text{Total energy consumption of sample size}}\ \mathrm{x}\ 100 \qquad \text{Equation 7}$$

Using this methodology, the energy audit reports were categorized according to the specific campus they fell under, and the same methodology was applied to each campus in order to attain their individual energy profile based on the sample size from the energy audit reports. All summarized data from the energy audit reports can be found in Appendix A: Campus Area’s and Energy Profiles.

Table 3-4: Energy Profiles from energy audits conducted by SEM Solutions of buildings on Upper Campus[1]

Leslie Commerce	**Energy Use**	**HVAC**	**Lighting Systems**	**Equipment**	**Other**
	Consumption Energy Index Breakdown	10%	69%	20%	1%
	2 447 802	244 780	1 688 983	489 560	24 478
GH Menzies	**Energy Use**	**HVAC**	**Lighting Systems**	**Equipment**	**Computing Systems**
	Consumption Energy Index Breakdown	39%	38%	21%	2%
	1 905 241	743 044	723 992	400 101	38 105
Snape	**Energy Use**	**HVAC**	**Lighting Systems**	**Equipment**	**Computing Systems**
	Consumption Energy Index Breakdown	35%	20%	28%	17%
	2 662 726	931 954	532 545	745 563	452 663
PD Hahn	**Energy Use**	**HVAC**	**Lighting Systems**	**Equipment**	**Other Services**
	Consumption Energy Index Breakdown	27%	37%	35%	1%
	3 423 633	924 381	1 266 744	1 198 272	34 236
RW James	**Energy Use**	**HVAC**	**Lighting Systems**	**Equipment**	**Other Services**
	Consumption Energy Index Breakdown	18%	47%	17%	18%
	547 253	98 506	257 209	93 033	98 506
Molecular Cell Biology	**Energy Use**	**HVAC**	**Lighting Systems**	**Equipment**	**Computing Systems**
	Consumption Energy Index Breakdown	39%	38%	22%	1%
	3 501 686	1 365 658	1 330 641	770 371	35 017
John Day	**Energy Use**	**HVAC**	**Lighting Systems**	**Equipment**	**Computing Systems**
	Consumption Energy Index Breakdown	34%	23%	28%	15%
	1 395 021	474 307	320 855	390 606	209 253
Robert Leslie Social Sciences	**Energy Use**	**HVAC**	**Lighting Systems**	**Equipment**	**Computing Systems**
	Consumption Energy Index Breakdown	15%	43%	17%	25%
	711 302	106 695	305 860	120 921	177 826

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[1] Consumption energy index breakdown indicates the percentage of the energy use type as well as the corresponding energy consumption of that energy use (kWh)

3.4 Scenario Development

Once the model had been disaggregated to the energy profile level for the types of buildings that fall under each campus, a reference case for the model was projected, and thereafter subjected to three different scenarios that were in succession to one another. The first scenario was to run the model through a projected decarbonisation of the Eskom grid electricity generation matrix. The second scenario was built on the results of scenario one, assessing the supply side option of adding rooftop photovoltaic (PV) generation available to UCT. The third and final scenario was built off the results of scenario two, , to consider demand side measures to reduce the overall energy demand of the university by introducing technologies and practices outlined by SEM Solutions.

3.4.1 Reference Case

The reference case in the model serves as the base on which the model is developed. The key features of the reference case are that trends in the supply and demand of electricity to the UCT estate remain the same. In another words, the energy demand of the institution increases as the area of the institution increases. Area expansion would be the only factor affecting the energy demand of the UCT Estate. This growth rate would be in accordance with UCT’s Integrated Development Framework, shown in Table 3-1.

Similarly on the supply side, the national Grid electricity generation matrix would remain constant at 2019 levels. Thus, the ratio between fuel source types that contribute towards electricity generation would be the same in 2050 as it was in 2019. The reference case exists to represent UCT’s energy demand and its emissions in a scenario in which current trends remain as they are.

3.4.2 Scenario 1: Decarbonisation of the National Grid

Scenario 1 builds off the assumptions of the reference case in a scenario where “UCT does nothing” and continues operations at current trends, however there is a change in the national grid electricity generation matrix. The ESRG team at UCT has produced energy system prediction data (grid matrices) under different scenarios of the country attempting to reach net zero. For the purposes of this model, the grid matrix that corresponded to South Africa making a fair contribution to an international mitigation effort for a 2^{o}C warming by 2050 was chosen as a not unlikely and illustrative estimate.

Table 3-5: National Grid electricity generation supply matrix under a 2ºC warming scenario taken from the SATIM model from the ESRG at UCT

Fuel type used in Electricity Generation	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**
Coal Bituminous	88.78%	88.78%	88.78%	88.78%	88.78%	88.78%	90.65%	88.58%	87.27%	86.39%	85.69%
Natural Gas	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Hydro	0.30%	0.30%	0.30%	0.30%	0.30%	0.30%	0.30%	0.30%	0.32%	0.31%	0.31%
Nuclear	6.39%	6.39%	6.39%	6.39%	6.39%	6.39%	4.49%	5.90%	6.22%	6.07%	5.13%
Diesel	0.20%	0.20%	0.20%	0.20%	0.20%	0.20%	0.20%	0.21%	0.22%	0.21%	0.21%
Solar	1.71%	1.71%	1.71%	1.71%	1.71%	1.71%	1.72%	2.14%	2.63%	3.25%	3.68%
Wind	2.62%	2.62%	2.62%	2.62%	2.62%	2.62%	2.64%	2.87%	3.35%	3.76%	4.97%
Fuel type used in Electricity Generation	**2023**	**2024**	**2025**	**2026**	**2027**	**2028**	**2029**	**2030**	**2031**	**2032**	**2033**
Coal Bituminous	84.31%	84.69%	85.47%	84.49%	84.64%	83.60%	80.51%	76.14%	70.75%	64.85%	59.27%
Natural Gas	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.17%	0.96%	1.41%	1.58%
Hydro	0.31%	0.31%	0.31%	0.31%	0.31%	0.30%	0.30%	0.30%	0.28%	0.27%	0.26%
Nuclear	6.54%	6.24%	5.42%	6.47%	6.39%	6.52%	5.90%	5.83%	5.57%	5.29%	5.12%
Diesel	0.21%	0.21%	0.21%	0.21%	0.21%	0.21%	0.20%	0.20%	0.19%	0.18%	0.18%
Solar	3.67%	3.64%	3.65%	3.62%	3.60%	4.55%	6.04%	5.97%	6.95%	9.14%	11.00%
Wind	4.95%	4.92%	4.93%	4.90%	4.86%	4.82%	7.04%	11.39%	15.30%	18.86%	22.60%
Fuel type used in Electricity Generation	**2034**	**2035**	**2036**	**2037**	**2038**	**2039**	**2040**	**2041**	**2042**	**2043**	**2044**
Coal Bituminous	54.26%	50.70%	46.43%	40.13%	34.15%	28.43%	22.96%	19.71%	16.59%	13.59%	10.70%
Natural Gas	1.99%	2.29%	2.64%	3.12%	3.66%	4.18%	4.67%	5.12%	5.55%	5.97%	6.36%
Hydro	0.25%	0.25%	0.24%	0.24%	0.23%	0.23%	0.22%	0.22%	0.21%	0.21%	0.20%
Nuclear	4.96%	4.83%	4.73%	4.66%	4.56%	4.46%	4.36%	3.42%	2.51%	1.64%	0.81%
Diesel	0.17%	0.17%	0.16%	0.16%	0.15%	0.15%	0.14%	0.12%	0.11%	0.09%	0.07%
Solar	13.33%	12.99%	13.60%	16.14%	18.04%	19.87%	21.61%	23.96%	26.22%	28.40%	30.49%
Wind	25.03%	28.78%	32.20%	35.55%	39.20%	42.69%	46.03%	47.45%	48.81%	50.11%	51.37%
Fuel type used in Electricity Generation	**2045**	**2046**	**2047**	**2048**	**2049**	**2050**					
Coal Bituminous	7.92%	7.00%	6.11%	5.27%	4.45%	3.67%					
Natural Gas	6.75%	6.80%	6.86%	6.91%	6.96%	7.01%					
Hydro	0.20%	0.20%	0.19%	0.19%	0.19%	0.18%					
Nuclear	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%					
Diesel	0.06%	0.07%	0.08%	0.09%	0.10%	0.11%					
Solar	32.50%	32.91%	33.31%	33.69%	34.06%	34.41%					
Wind	52.58%	53.02%	53.44%	53.85%	54.24%	54.62%					

Table 3-5 indicates the National Grid electricity generation supply matrix under a 2ºC warming scenario taken from the SATIM model from the ESRG at UCT (Appendix B1: Scenario 1 – Decarbonization of the National Grid, Table 7-11). Essentially, it indicates the contribution of each electricity generation subsector. For example, according to this model projection, in 2012, the coal industry was responsible for approximately 89% of all the electricity generated in South Africa.

This grid matrix was incorporated under the 'Transformation' branch in the model (see Figure 3-5).

3.4.3 Scenario 2: Supply Side Management

Scenario 2, which builds on Scenario 1, introduces a supply side condition based on UCT's proposed plans to install solar polar on the campus.

In 2020, UCT had contracted Arup (Pty) Ltd to investigate the feasibility of the introduction of solar photovoltaic (PV) system installations at selected buildings across its campuses. Given the need to act on environmental sustainability and the trend toward the utilization of renewable energy resources, UCT underwent this investigation to reduce their carbon emissions and subvent energy supply by installing photovoltaic systems. The intention was aimed to reduce the demand and pressure UCT places on the utility grid, reduce annual operational costs and to provide the means necessary to facilitate research work in addition to promoting renewable energy and environmental sustainability to the broader stakeholders of the university.

The investigative process consisted of three phases. The first task of phase one entailed the selection of the 30 most suitable sites for PV installation based on estimated available area and heritage ratings. Thereafter, site visits were conducted to assess the adequacy of the electrical infrastructure and structural components of the selected buildings for PV system installations. An indicative feasibility score was calculated for each building based on the electrical and structural adequacy in addition to other factors such as the potential visual impact of the PV installation. Phase 3 of their study consisted of conducting a financial feasibility assessment of introducing PV system installations to the selected buildings.

Table 3-6 summarizes the key results of the UCT PV feasibility investigation conducted by the consultancy, Arup (Pty) Ltd.

Table 3-6: Summary of key results of the UCT PV feasibility Investigation

Campus	Number of buildings	Cumulative System Size (kWp)	Cumulative Capital Cost (R)	Cumulative Opex Costs over 25 years (R)	Annual Opex Cost (R)	Average ROI (%)	Average Payback Period (Years)	Average feasibility (%)
Upper Campus	9	736.4	9 921 943	10 324 420	412 977	6.61	6.02	71.67
Middle & Lower Campus	7	889.2	11 918 361	10 478 035	419 121	3.59	9.42	73.90
Off Campus Residences	6	509.5	6 822 915	5 988 734	239 549	3.10	8.32	75.11
Health Science Campus	3	154.5	2 067 343	1 795 199	71 808	5.00	6.66	77.56
Hiddingh Campus	1	35.3	472 344	408 390	16 336	1.80	8.80	65.33
Breakwater Campus	3	221.94	2 969 750	2 587 654	103 506	3.07	8.07	66.89
Total / Average	**29**	**2547**	**34 172 656**	**31 582 432**	**1 263 297**	**3.86**	**7.88**	**71.74**

As summarized in Table 3-6, Arup (Pty) Ltd established that the UCT estate would be able to install 2547 kWp of PV systems across its various campuses, with reasonable feasibility.

This data was utilized in Scenario 2 by incorporating the installation of this system where it was assumed that 510 kWp PV systems would be installed on the UCT estate from 2023 until 2027, such that it would fulfil the total 2547 kWp PV system that was deemed feasible by the external consultants. This supply side action was incorporated into the ‘Transformation’ branch of the model under the addition of solar polar.

3.4.4 Scenario 3: Demand Side Management

The final scenario in the model introduces demand side interventions which was aimed at reducing UCT’s overall energy demand. As previously mentioned in this dissertation, SEM Solutions conducted 16 energy audit reports on various buildings at UCT. The energy audit reports were not only used to establish energy profiles for each individual campus, but also assessed what type of measures could be implemented in order to reduce the overall energy consumption of the assessed buildings.

The energy audit reports found reduction measures could be implemented in HVAC, Lighting Systems and Water Heating. These reduction measures were grouped according to payback times of short (2 years), medium (5 years) and long (10 years). A summary of these findings is reported in Table 3-7.

Table 3-7: Summary of demand side reduction measures based on the energy audits conducted by SEM Solutions

	Energy demand reduction (kWh/year)			
Technology/Timescale	**Short**	**Medium**	**Long**	**Total**
HVAC	473 510	379 322	75 822	928 654
Lighting	-	2 621 006	1 324 448	3 945 454
Water Heating	-	-	3 051	3 051
Total	473 510	3 000 328	1 403 321	4 877 159

Based off these findings, UCT would save approximately 4.9 GWh annually after all these reduction measures be implemented on these 16 buildings (post 2032). Similar to how the energy audits served as a sample to establish the energy profile of the UCT estate, it was assumed that these reduction methods on these 16 buildings could be applied to the entire campus.

The original consumption column in Table 3-8 summarizes the total energy consumption of the 16 energy audit reports by energy use (HVAC, Lighting and Water Heating). Table 3-8 was produced by applying the energy reductions outlined in Table 3-7, and additionally represents this as a percentage reduction of the original consumption pre-implementation of the energy reduction measures. Scenario 3 was thus developed by incorporating this percentage reduction into the model by applying it to the energy uses for HVAC, Lighting and Water Heating for UCT's academic type buildings.

Table 3-8: Reduction in UCT energy consumption under the application of demand side reduction interventions, reported in kWh and as a percentage reduction of its original total

Technology/Time scale	Original Consumption	Short	Medium	Long
HVAC	8 011 061	7 537 551	7 158 229	7 082 407
Lighting	10 234 904	10 234 904	7 613 897	6 289 450
Water Heating	52 581	52 581	52 581	49 530

Technology/Timescale	Short	Medium	Long
HVAC	94.09%	89.35%	88.41%
Lighting	100.00%	74.39%	61.45%
Water Heating	100.00%	100.00%	94.20%

The detailed list of reduction measures and technologies reported in the energy audit reports can be found in Appendix B1: Scenario 3 – Demand Side Management under Table 7-12.

3.5 Ethical considerations and clearance

The study involved engaging with numerous stakeholders across the UCT institution in order to source data and insights. These include key management involved in UCT Finance, Environmental Management Committee (EMC), Student Housing and Resident Life, the ESRG and members of the Khusela Ikamva Initiative. The ethical issues that may arise from this relate to the study co-producing knowledge to inform the construction of the energy systems model. It was thus deemed important to obtain the informed consent of data providers and, if requested, to ensure the anonymity of respondents; obtaining permission to use secondary datasets; and storing sensitive information. Consent forms will be used for all information reported, discussed or knowledge that was co-produced.

Ethics clearance was granted by the EBE Faculty’s Ethics-in-Research Committee, for conducting the research in this dissertation, which can be found in 7.3 Appendix C: Ethics Clearance.

4 CHAPTER FOUR: RESULTS AND DISCUSSIONS

This chapter of the dissertation first reports the results from the data analysis of the energy audit reports, mainly into the disaggregation of the UCT estate into its unique campuses, and then further into its building types. Thereafter, the energy profiles of these building types will be reported.

The second category of results are the modelled scenarios: first reporting the reference case and comparing this to UCT's historical data. The baseline scenario (Scenario 1) simulates the effects of the national grid decarbonizing on UCT's Scope 2 emissions. Scenario 2 simulates the effects of incorporating the supply side intervention of installing solar photovoltaic panels on the campus and its impact on UCT's Scope 2 emissions. The third and final scenario simulates the effects of incorporating demand side energy-efficiency interventions to reduce energy use on HVAC, Lighting and Water Heating, and the subsequent impacts this has on UCT's overall energy consumption and subsequently its Scope 2 emissions.

4.1 Stakeholder engagements

A large part of this dissertation were the qualitative insights through site assessments gained from engaging with stakeholders at various levels within UCT management. Much of the sourced data that was utilized in the construction of the energy systems model was gained from key members of staff at UCT. The key findings of these engagements are presented below:

4.1.1 Institutional arrangements for Sustainability

In previous studies of general awareness of sustainability at UCT, the institution had shown that much of this information had been isolated and in pockets (in research groups) and additionally, sustainability initiatives seemed to occur 'under-the-radar' and get reported on after the project has concluded (Mandalia, 2018). Previously, UCT budgeted around R1.5 million towards campus sustainability, however this had come from the Properties and Services (P&S) budget and accounted mainly for reporting – being the Carbon Footprint Report and ISCN-GULF (Mandalia, 2018). Mandalia (2018) had found that that budget was the only one used directly for sustainability initiatives, which had indicated a lack of strategic plans and responsibility for improving environmental sustainability at the institution. Furthermore, because a university is bureaucratically structured, top-level administration must supervise the operations of numerous departments and then allocate resources - money, labour, and other assistance - as needed. Various processes will be running in parallel at the same time, and while there will be autonomy, some coordination throughout the organization is required. Essentially, in the past, UCT did not possess a central office to co-ordinate campus sustainability between the UCT community (Mandalia, 2018).

In conducting this study, it was evident that there had been many improvements made on the awareness of campus sustainability initiatives. Many of the UCT staff that were engaged with were not only aware of some sort of campus sustainability initiative but associated with these projects either indirectly or directly. One can deduce that this is owing to the institution creating a Directorate in the Office of the Vice Chancellor in 2018, and in April 2019, appointing a Director for Environmental Sustainability to lead this Directorate. In doing so, it is evident that UCT’s sustainability efforts are more organized and cohesive.

A further step in the right direction towards uniting the different levels of management and governance on the campus was the creation of the Khusela Ikamva Initiative. Launched in 2020 and co-ordinated by the Director for Environmental Sustainability, the aim of the project is to catalyst the transformation of UCT into a sustainable campus. The project seeks to carry out its aims by establishing a community of practice that is informed by co-producing knowledge and research from all UCT stakeholder levels (including students, academic staff in various departments, university management and finance etc.). The project defines itself on incorporating extensive and inclusive engagement with the university community, and by establishing living lab interventions on the campus, that serve as a ‘proof-of-concept’. The proponents of the project intend on “assessing the environmental, financial, and social implications of five major issues on the UCT campus: energy/carbon, water, waste, wildlife, and social responsiveness”. The project aims to include research that will establish the viability of certain features in order to support and expand on UCT’s ESS policy, and subsequently to be turned into proof-of-concepts that will be tested on campus using a Living Lab method. As a result, the project aims to play a critical role in transforming UCT's institutional fabric into a more sustainable campus, not only via the physical fabric of the campus but also through the social fabric that is the campus community. The initiative received R10 million over five years, with R2 million allocated each year, and includes multiple postgraduate research opportunities (one being this very dissertation). Although it is still too early to assess the overall success and impact of the project, it has made significant progress in connecting various departments within the UCT community through the sub-projects of the Khusela Ikamva Initiative (as shown in Figure 4-1). The establishment of the Khusela Ikamva Initiative as well as its allocated budget has already shown the institutions dedicated commitment towards sustainability that it has lacked in the past.

Through this, there have been regular meetings and collaborations held between academic departments, operational staff, managerial staff and students. This indicates an initial step of establishing a community of practice when tackling campus sustainability issues.

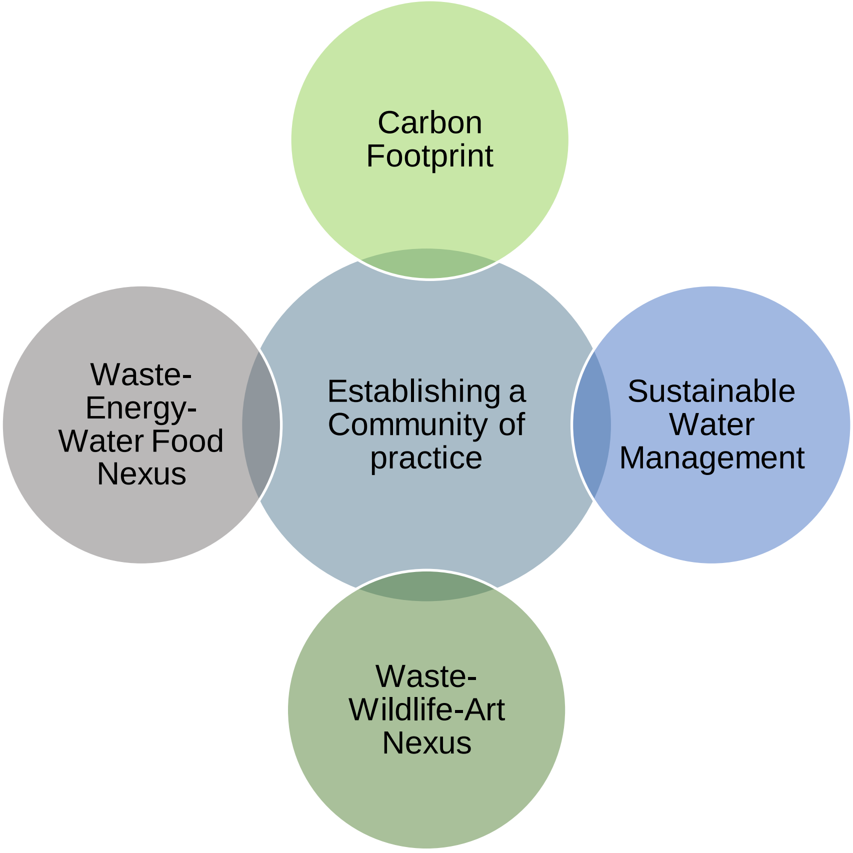


Figure 4-1: Khusela Ikamva Initiative project themes

Campus sustainability has taken a larger role on campus as well as online. Campus sustainability initiatives are being well advertised through the institution's websites and social media platforms. This indicates the institution's increased role in creating awareness of its sustainability initiatives in order to engage with the entire UCT community and not just the academic staff.

4.1.2 Insights from stakeholders

Conducting the data collection process of this dissertation included engaging with stakeholders across disciplines – from different academic departments to operational and managerial staff. In doing so, valuable insights into the operation and maintenance of UCT's infrastructure were able to feed the assumptions that the energy systems model was constructed upon. A key insight was the responsiveness of UCT's operational staff in assisting with the data collection process, in that they were well equipped to answer questions involving their line of operation. The insights gained through these stakeholder engagements can be summarized below:

1. Through engagements with UCT's Properties and Services (P&S) staff, the research found that most of UCT's buildings are old and running inefficiently. With regards to lighting, although there has been planned maintenance and retrofits, much of the lighting in older buildings is not up to date with the latest technologies (LEDs). Additionally, most of the lighting on the campus does not run on occupancy sensors or timers. With the exception of the newer academic buildings, most buildings (especially residences) operate their lighting manually.
2. With regards to water heating, the institution performs relatively well in that most of its residences operate off heat pumps as opposed to individual geysers (the exception of this are the large Liesbeeck and Forest Hills residences, with a few smaller Tier 3 residences around the campus).

4.2 Disaggregation of the UCT Estate

4.2.1 Disaggregation of Main Campus into Upper, Middle and Lower Campus

As reported in Table 3-3, the Main Campus was split into Upper, Middle and Lower Campus based on area ratios, which were then applied to the total energy consumption of Main Campus in order to attain the estimated energy consumption for Upper, Middle and Lower Campus respectively. This resulted in Upper Campus being responsible for an estimated 67% of the annual total energy consumption of Main Campus, with Middle and Lower being responsible for 14% and 19% respectively.

This ratio was applied to the historical reported data from the UCT Carbon Footprint reports, thus resulting in Table 4-1.

Table 4-1: Yearly energy consumption of a disaggregated Main Campus into Upper, Middle and Lower Campus

Location /Year	Main Campus	Upper Campus	Middle Campus	Lower Campus
2012	45 099 590	30 289 196	6 134 921	8 675 473
2013	45 300 860	30 424 370	6 162 300	8 714 190
2014	47 041 102	31 593 129	6 399 026	9 048 947
2015	46 468 176	31 208 348	6 321 091	8 938 738
2016	44 216 343	29 696 001	6 014 772	8 505 569
2017	45 361 862	30 465 340	6 170 598	8 725 924
2018	44 362 046	29 793 857	6 034 593	8 533 597
2019	42 799 564	28 744 483	5 822 047	8 233 034

UCT currently only possesses metred data for the entire Main Campus and does not currently possess metred data for the individual Upper, Middle or Lower Campuses. Thus, the disaggregated data in Table 4-1 should be regarded as a first estimate of the energy consumption of these individual campuses.

4.2.2 Disaggregation of Campuses into Academic vs Residence type buildings

This section reports the results of the disaggregation of the relevant campuses into Academic vs Residence Type buildings.

Based on the review of building types on each campus, it was found that Upper Campus, Middle Campus, Lower Campus and Medical Campus possessed both academic and residence building types. The areas of these buildings were used to determine the split between academic type buildings and residence type buildings. Like the disaggregation of the Main Campus into Upper, Middle and Lower Campus based on an area ratio, it was assumed that the ratio in area of academic vs residence type buildings would equate to the ratio in total energy consumption of that campus, the result of which can be seen in Table 4-2 (see Appendix A: Campus Area's and Energy Profiles).

Table 4-2: Floor-space shares of Academic Type Buildings vs Residence Type Buildings on each campus

	Academic Type Buildings	Residence Type Buildings	Refer to
Upper Campus	92.72%	7.28%	Appendix A1: Upper Campus
Middle Campus	75.40%	24.60%	Appendix A2: Middle Campus
Lower Campus	38.45%	61.55%	Appendix A3: Lower Campus
Medical Campus	92.40%	7.60%	Appendix A4: Medical Campus

As expected, Academic Type buildings were buildings contributed most to the total area of Upper, Middle and Medical Campus, as these campuses are dedicated mostly towards teaching spaces. Lower Campus, which was mainly designated to house students of the institution, expectedly consisted of more residence type buildings than academic type buildings.

4.2.3 Energy Profiles of each campus

This section reports the energy profile results of each individual campus. As outlined in ‘3.3.3 Disaggregation of Building Types into distinct Energy profiles’, 16 energy audits, that were conducted by SEM Solutions, were used as a sample size to estimate the energy profile of academic and residence type buildings under each campus.

Upper Campus utilized eight energy audit reports to estimate the energy profile of the academic type buildings that exist on the campus (Table 3-4). The estimated energy profile of academic type buildings on Upper Campus is reported in Table 4-3. From this estimation, lighting systems were found to consume the most energy in academic type buildings on Upper Campus.

Table 4-3: Energy Profile of Academic Type Building’s on Upper Campus

UPPER CAMPUS					
	HVAC	**Lighting Systems**	**Equipment**	**Computing Systems**	**Other**
Split for LEAP Base Case	29.46%	38.73%	25.36%	5.50%	0.95%

Middle Campus utilized three energy audit reports to estimate the energy profile of the academic type buildings that exist on the campus (supporting information can be found in Appendix A2: Middle Campus, Table 7-3). The estimated energy profile of academic type buildings on Middle Campus is reported in Table 4-4. From this estimation, lighting systems were found to consume the most energy in academic type buildings on Middle Campus, with HVAC responsible for consuming the second most energy on the campus.

Table 4-4: Energy Profile of Academic Type Building's on Middle Campus

MIDDLE CAMPUS					
	HVAC	**Lighting Systems**	**Equipment**	**Computer Rooms**	**Water Heating**
Split for LEAP Base Case	34.66%	39.26%	11.91%	13.86%	0.31%

Lower Campus did not have any energy report audits done on its academic type buildings, hence the energy profile of the academic type buildings that exist on Lower Campus would adopt the same profile as the academic type buildings that exist on Middle Campus (supporting information can be found in Appendix A2: Middle Campus, Table 7-3). The difference in these energy profiles is that academic type buildings on Lower Campus were assumed to have no water heating, and thus this energy use would be absorbed into the residence type buildings that exist on Lower Campus (Table 4-5).

Table 4-5: Energy Profile of Academic Type Building's on Lower Campus

LOWER CAMPUS				
	HVAC	**Lighting Systems**	**Equipment**	**Computer Rooms**
Split for LEAP Base Case	34.66%	39.26%	12.22%	13.85%

Medical Campus utilized four energy audit reports to estimate the energy profile of the academic type buildings that exist on the campus (supporting information can be found in Appendix A4: Medical Campus, Table 7-6). The estimated energy profile of academic type buildings on Medical Campus is reported in Table 4-6. From this estimation, lighting systems were found to consume the most energy in academic type buildings on Medical Campus, with HVAC being the second greatest energy consumer on the campus.

Table 4-6: Energy Profile of Academic Type Building's on Medical Campus

MEDICAL CAMPUS					
	HVAC	**Lighting Systems**	**Equipment**	**Computer Rooms**	**Other Services**
Split for LEAP Base Case	29.74%	37.02%	16.98%	15.42%	0.84%

ICTS on Main, UCT's data centre, did not have any available energy audit reports, hence typical energy profiles of data centres were adopted (supporting information can be found in Appendix A5: ICTS on Main, Figure 7-3).

Table 4-7: Energy Profile of Academic Type Building's on ICTS on Main

ICTS ON MAIN				
	HVAC	**Servers**	**Storage Drives**	**Network**
Split for LEAP Base Case	43.00%	43.00%	11.00%	3.00%

Off Campus Residences utilized one energy audit report to estimate the energy profile of the residence type buildings that exist (supporting information can be found in Appendix A6: Off Campus Residences, Figure 7-4). The estimated energy profile of Off Campus Residences is reported in Table 4-8Table 4-6.

The residence rooms contribute to the majority of the building's energy consumption at approximately 53%. This is due to the large number of rooms with little common area, the use of efficient water heating technology and no centralised air conditioning. The common area lighting contributes approximately 18% made up of the passage, kitchen, offices and facilities lighting. There is no control of the rooms themselves, however, it was noted that the students have the following general equipment: 2kW fan heater, a minibar fridge, and a laptop.

As there was only one energy audit conducted on a residence type building, this energy profile was adopted on campuses that also possessed residence type buildings (Upper Campus, Middle Campus, Lower Campus and Medical Campus).

Table 4-8: Energy Profile of Off Campus Residences

OFF CAMPUS RESIDENCES				
	Residence Rooms	**Lighting Systems**	**Heat Pumps**	**Kitchen**
Split for LEAP Base Case	53.00%	18.00%	8.00%	21.00%

GSB utilized one energy audit report to estimate the energy profile of the academic type buildings that exist on the campus (supporting information can be found in (Appendix A7: Graduate School of Business (GSB), Figure 7-5). The estimated energy profile of academic type buildings on Medical Campus is reported in Table 4-9. From this estimation, lighting systems were again found to consume the most energy in academic type buildings on Medical Campus, with HVAC being the second greatest energy consumer on the campus.

Table 4-9: Energy Profile of GSB

GSB					
	HVAC	**Lighting Systems**	**Equipment**	**Computing Systems**	**Water Heating**
Split for LEAP Base Case	23.00%	38.00%	17.00%	6.00%	16.00%

Hiddingh Campus did not have any energy report audits done on its academic type buildings (the only type of buildings present on the campus), hence the energy profile of the academic type buildings that exist on Hiddingh Campus would adopt the same profile as the academic type buildings that exist on Upper Campus. This was based off the age and type of the buildings present on Hiddingh and Upper Campus being relatively similar (with the exception of the new buildings on Upper Campus, which would alter the end use energy profile data).

Table 4-10: Energy Profile of Hiddingh Campus

HIDDINGH CAMPUS					
	HVAC	**Lighting Systems**	**Equipment**	**Computing Systems**	**Other**
Split for LEAP Base Case	29.46%	38.73%	25.36%	5.50%	0.95%

4.2.4 Notable patterns on campus energy profiles

Using the total energy consumption for each campus and their unique energy profiles, Figure 4-2 was developed to showcase the energy profile of the entire UCT estate. Notably, lighting is estimated to be responsible for 31% of the total energy consumption, with HVAC likely responsible for consuming 22% of the university's total energy purchases.

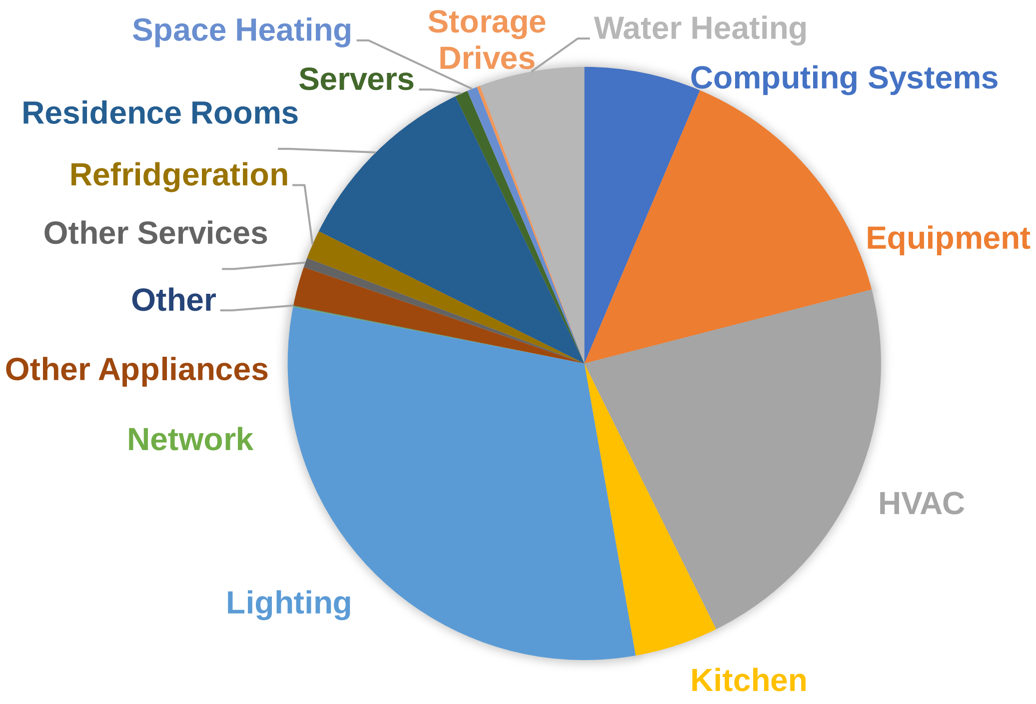


Figure 4-2: Summarized energy profile of the entire UCT Estate based on 2019 energy audit data

4.3 Reference Case

This section of the dissertation presents the simulated model of UCT's energy demand from 2012 – 2019, based on a campus level breakdown, its building type as well as its energy use. The reference case serves as the base on which the model is developed. The key feature of the reference case is that it simulates UCT's energy consumption under the assumption that its supply and demand continue at current trends.

4.3.1 Historical Baseline

Figure 4-3 illustrates the modelled historical baseline results from LEAP. As expected, Upper Campus was the main energy consumer out of all the campuses during 2012 to 2019, as it is the largest campus by area (225 257 m^2) and possesses more buildings than any other campus on the UCT estate.

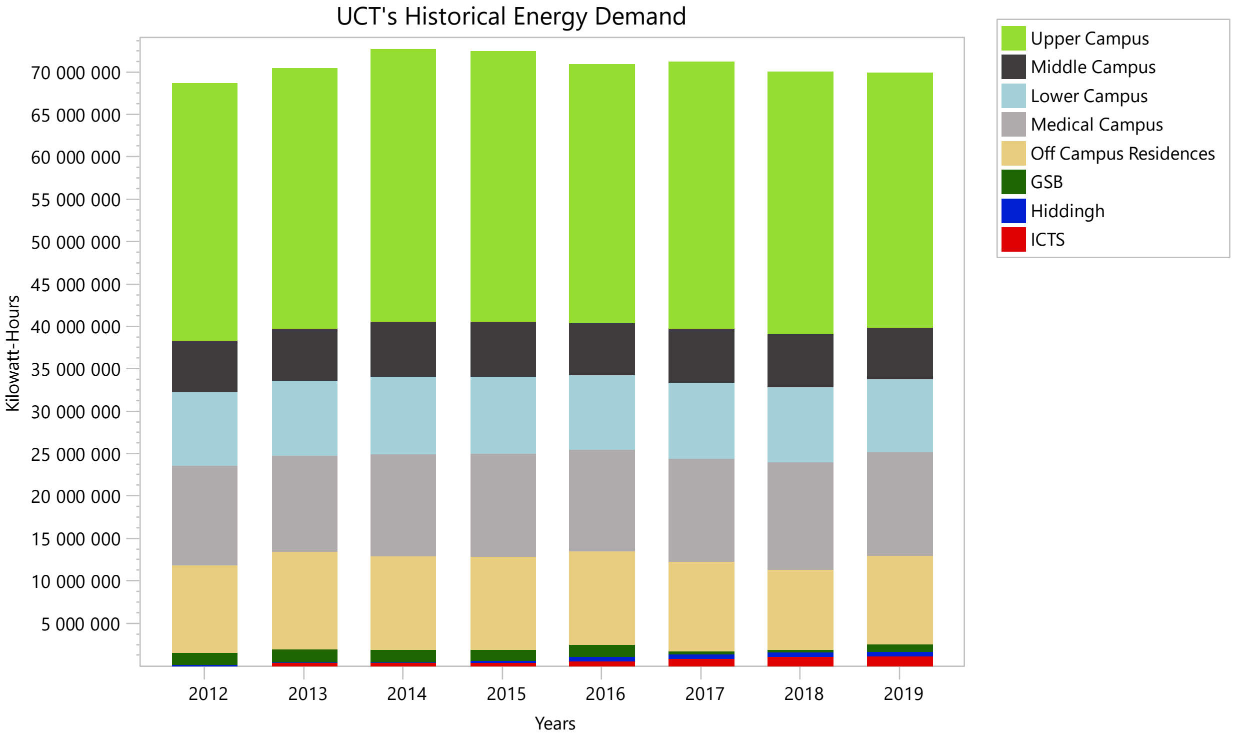


Figure 4-3: UCT's simulated historical energy demand (2012 - 2019)

Figure 4-4 illustrates UCT's modelled historical energy demand, however, shows the disaggregation on this energy demand into building types and then further into energy use. It should be noted that Tier 1, Tier 2, and Tier 3 all fall under residence building types. Tier 1 residences are catered residences, while Tier 2 and 3 are self-catered residences. These were separated to indicate what types of residences on the estate consume the most energy.

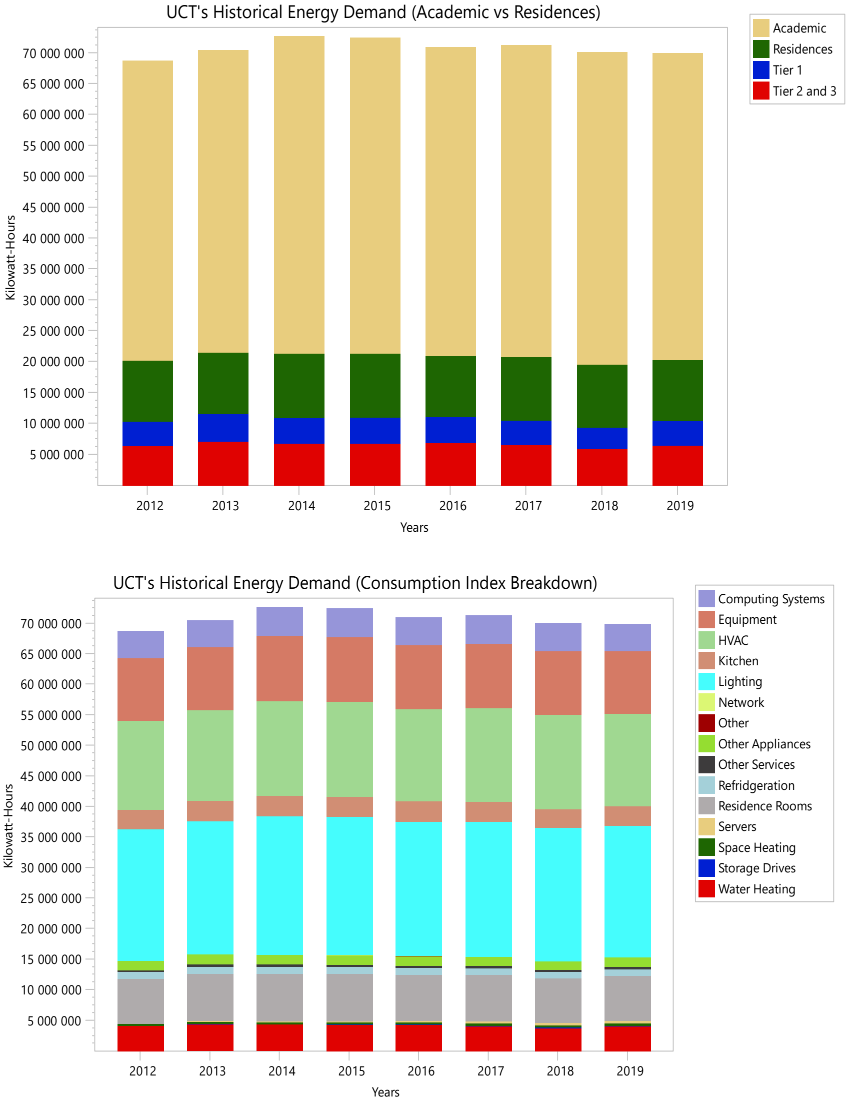


Figure 4-4: UCT's simulated historical demand by building type and energy use (2012 - 2019)

4.3.2 Level of accuracy of the LEAP model

In comparing UCT’s historical energy demand versus the simulated energy demand by LEAP, the percentage difference between these two sets of results increases over time, at a rate of 0.6% per year (Figure 5-1). The baseline model currently does not include energy efficiency improvements that occurred during this period, and thus the model over-estimates the institutions energy demand. However, this dissertation argues that it is useful to model all growth beyond this point with zero efficiency gains (in this particular reference case). In reality, there is always progress with energy efficiency, and so the model presented, and the model projected, demonstrates worst-case scenarios (to attain a reasonable inclusion of efficiency would be to reduce all projected energy demand by 4.3%). This will be discussed further in the conclusions and recommendations chapter of this dissertation.

4.3.3 Reference Case: Projected Model to 2050

The key features of the reference case are that trends in the supply and demand of electricity to the UCT estate remain the same. As previously stated, the simulation model was developed to represent the institution's energy consumption as a factor of its area (kWh/m^2), thus any growth in area of the institution would result in a growth in the energy demand of the institution. The area expansion growth rates outlined in Table 3-1, in accordance with UCT's Integrated Development Framework, were incorporated into the model to project the institution's future energy demand, shown in Figure 4-5. Notably under these assumptions, the institution's energy demand increases to approximately 81 GWh in 2050 from 70 GWh in 2019.

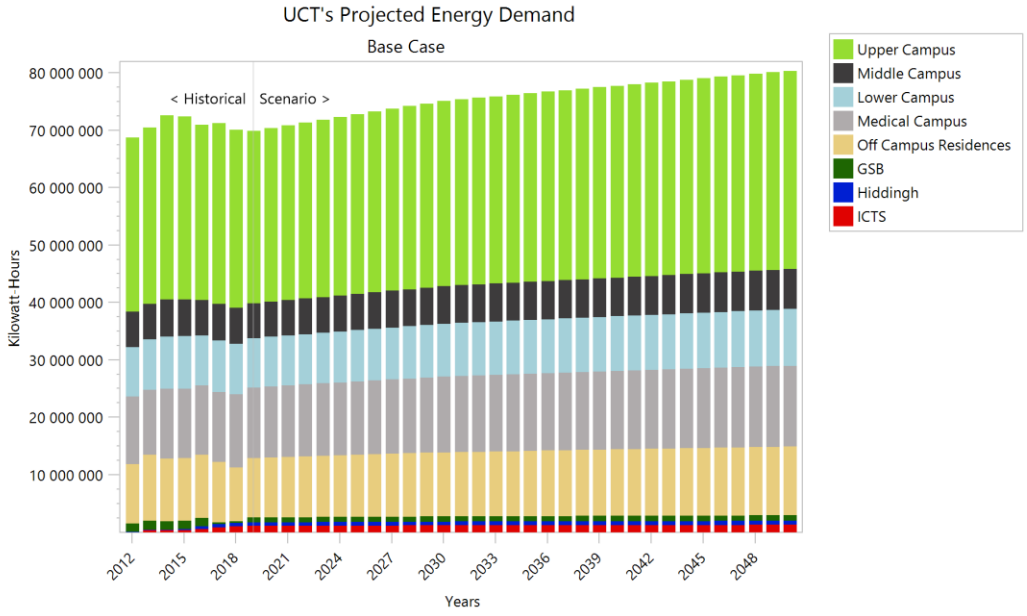


Figure 4-5: UCT's projected energy demand (Reference Case)

Corresponding to the institution's modelled energy demand is its projected carbon dioxide equivalent (CO_2e) emissions, as illustrated in Figure 4-6. Notably under these assumptions, the institution's emissions would increase to 83 807 tons per annum in 2050 from 72 914 tons in 2019.However, it is clear that this should not be considered a baseline, as the carbon intensity of electricity from the national grid will not remain unchanged.

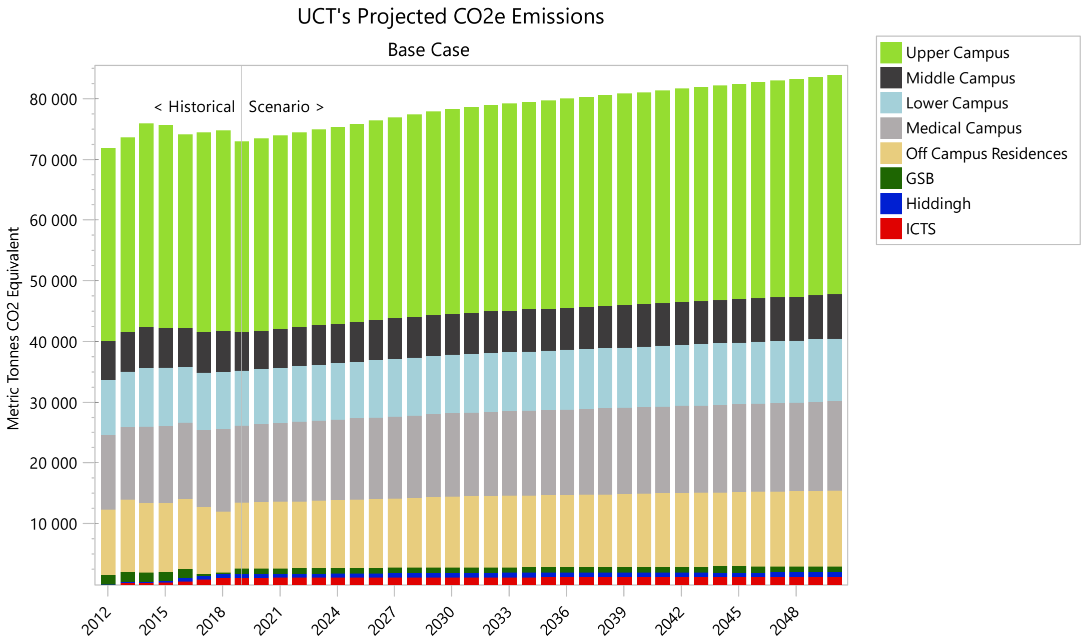


Figure 4-6: UCT's projected CO_2e emissions (Reference Case)

4.4 Scenario 1: Decarbonisation of the National Grid

Built off the assumptions in the reference case, Scenario 1 illustrates UCT's Scope 2 emissions under the decarbonisation of the national grid by using a national grid matrix that corresponds to South Africa making a fair-share mitigation attempt to keep to a 2°C warming by 2050 (produced by The Energy Systems Research Group (ESRG) at UCT). Table 3-5 indicates the National Grid electricity generation supply matrix under a 2°C warming scenario taken from the SATIM model from the ESRG at UCT (Appendix B1: Scenario 1 – Decarbonization of the National Grid, Table 7-11). This national grid matrix was incorporated into the transformation node of the model, illustrated in Figure 4-7. As can be seen, the use of coal as a fuel source for electricity generation decreases from approximately 89% in 2019, to 76% in 2030, and finally reducing to under 4% by 2050. To supplement this, it can be seen that solar and wind power will become the dominant energy sources for electricity generation by 2050 under a 2°C warming scenario.

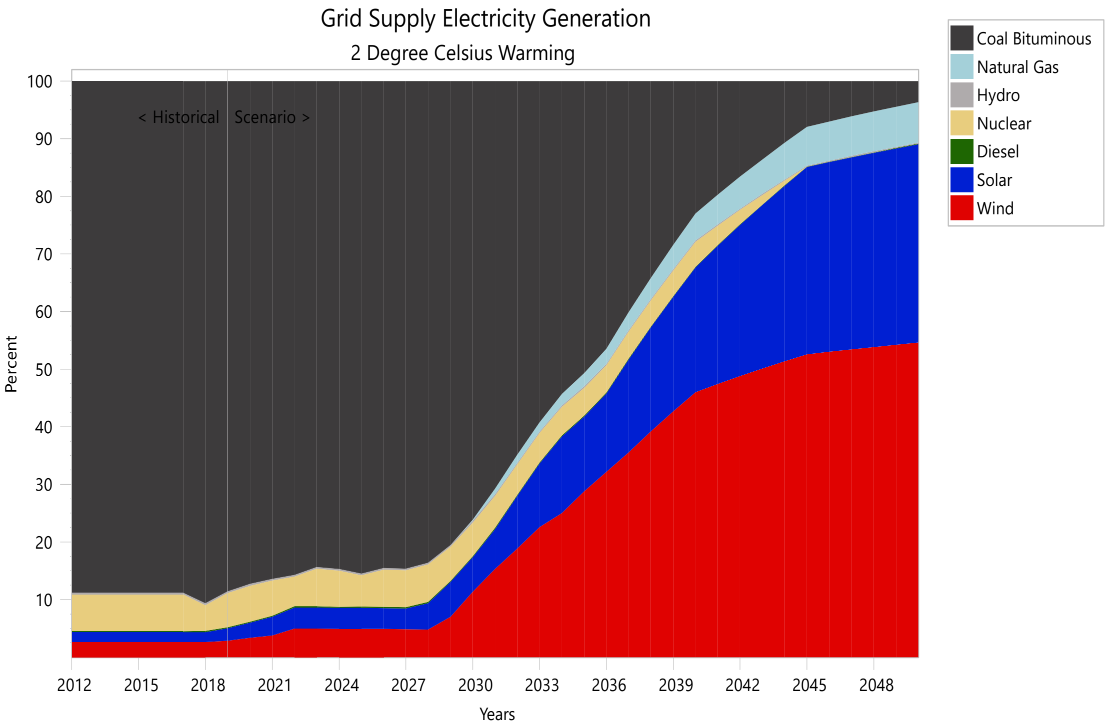


Figure 4-7: National Grid electricity generation supply matrix under a 2°C warming scenario taken from the SATIM model from the ESRG at UCT

4.4.1 Projected Scope 2 emissions

Figure 4-8 illustrates UCT's Scope 2 emissions by campus level whereby the national grid decarbonises in accordance with a 2ºC warming scenario. There is a significant impact on UCT's Scope 2 emissions from 2028 onwards. In 2019, in this scenario, UCT would account for 67 429 tons per annum of CO_2e Scope 2 emissions in 2030, with this reducing to 6 239 tons per annum of CO_2e emissions by 2050. Thus, should the national grid decarbonize in this manner, UCT would have significantly reduced their Scope 2 emissions while continuing operations at current trends. However, it is important to note that the institution will only reduce its Scope 2 emissions by half by 2038. Hence, should the university want to reduce their Scope 2 emissions by half by 2030, additional measures must be implemented to reduce the institutions emissions at a quicker rate.

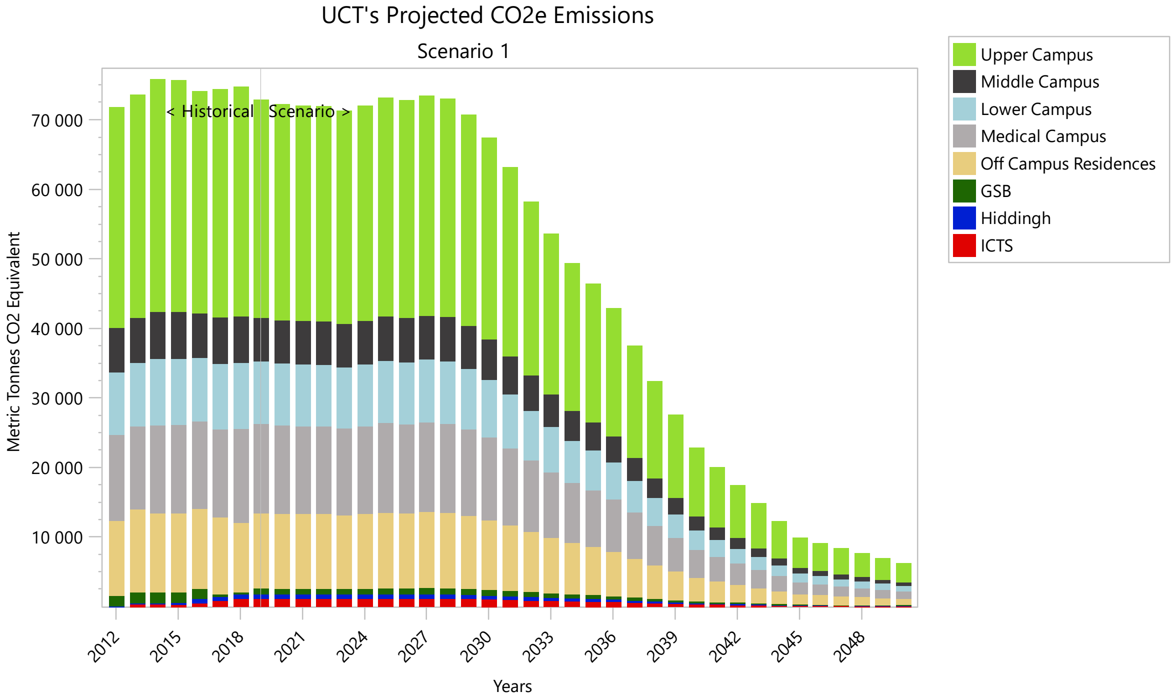
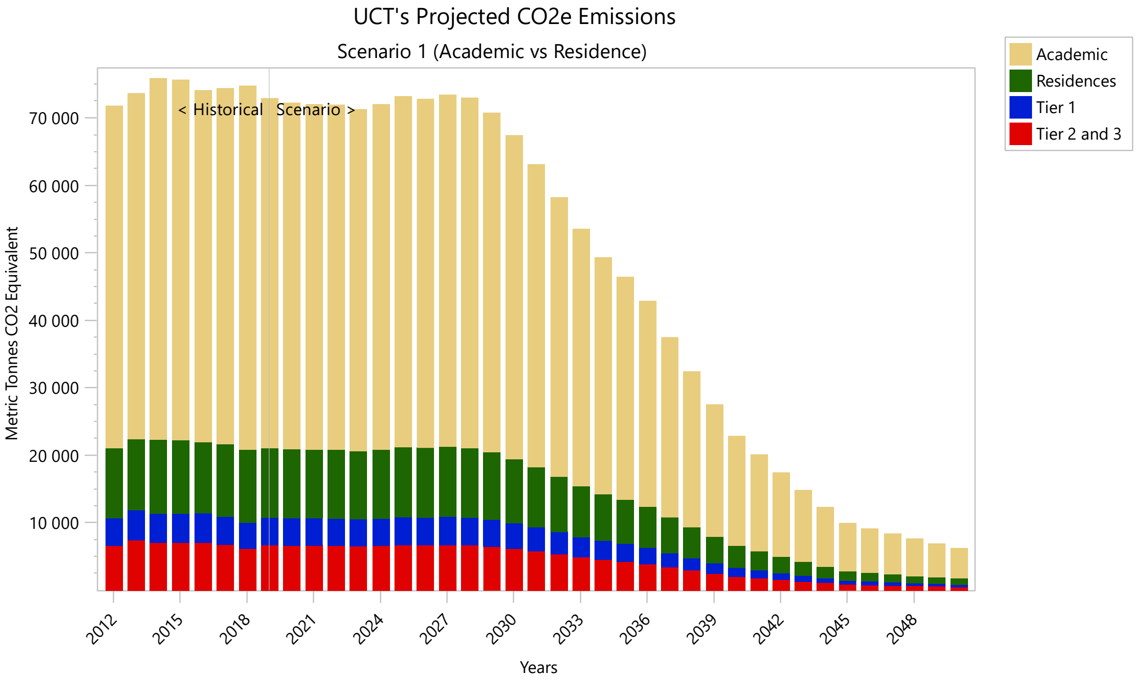


Figure 4-8: UCT's projected CO_2e emissions under Scenario 1 (Campus Level)

Figure 4-9 reports these emissions based on building type and by energy use.



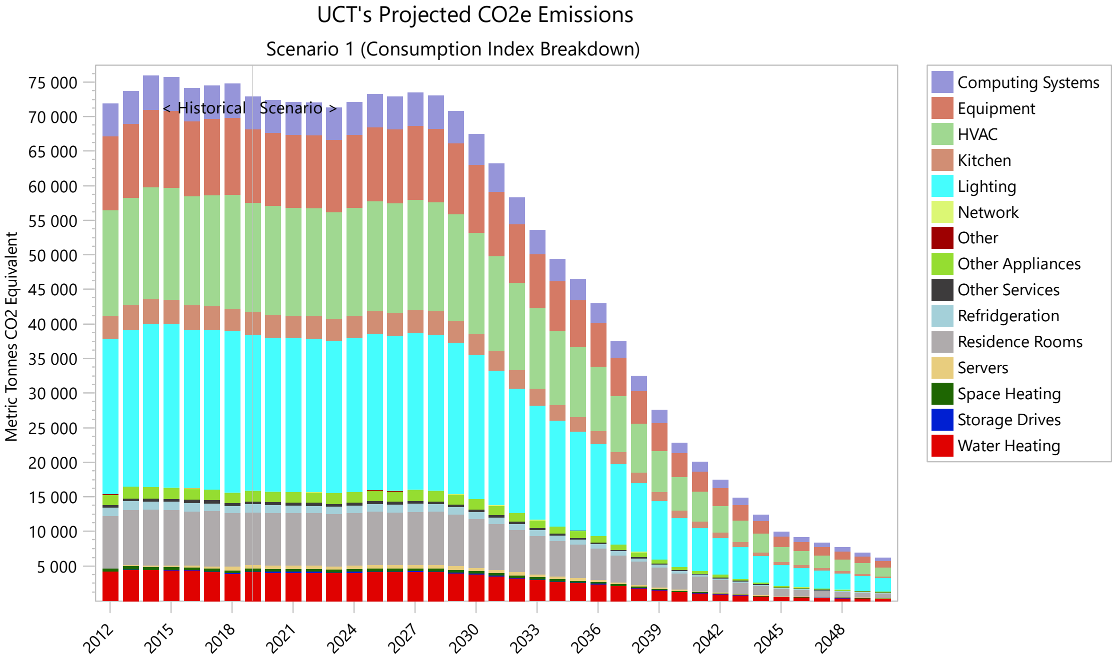


Figure 4-9: UCT's projected CO$_2$e emissions under Scenario 1 (Building Type & Energy Profile Level)

4.5 Scenario 2: Supply Side Management

4.5.1 Projected Scope 2 emissions

Scenario 2, which builds on Scenario 1, introduces a supply side condition based on UCT's proposed plans to install solar power on the campus. The intention of introducing self-generation is aimed at reducing the demand that UCT places on the utility grid, to reduce annual operational costs and to provide the means necessary to facilitate research work in addition to promoting renewable energy and environmental sustainability to the broader stakeholders of the university. Table 3-6 reports the key results of the UCT PV feasibility investigation conducted by Arup (Pty) Ltd, where it was found that the institution was able to install a 2547 kWp PV system across its various campuses, with reasonable feasibility.

If UCT were to instal 510 kWp PV systems each year, from 2023 until 2027, its Scope 2 emissions would look as shown in Figure 4-10 below.

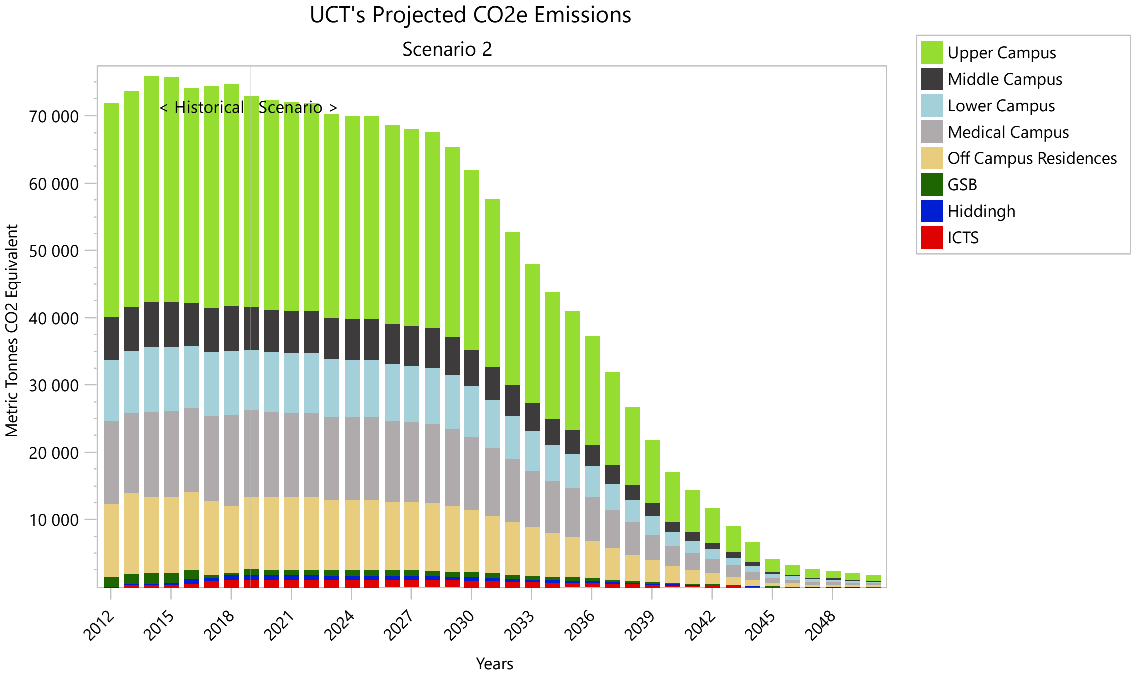


Figure 4-10: UCT's projected CO$_2$e emissions under Scenario 2 (Campus Level)

Under Scenario 2, UCT produces 61 901 tons per annum of CO$_2$e emissions in 2030, with this reducing to approximately 1 773 tons per annum of CO$_2$e emissions by 2050. Although an improvement from Scenario 1, under Scenario 2 the institution will only reduce its Scope 2 emissions by half by 2037 (one year earlier than in Scenario 1). Hence, should the university want to keep want to reduce their Scope 2 emissions by half by 2030, additional measures must be implemented to reduce the institutions emissions at a quicker rate.

Figure 4-11 reports these emissions based on building type and by energy use.

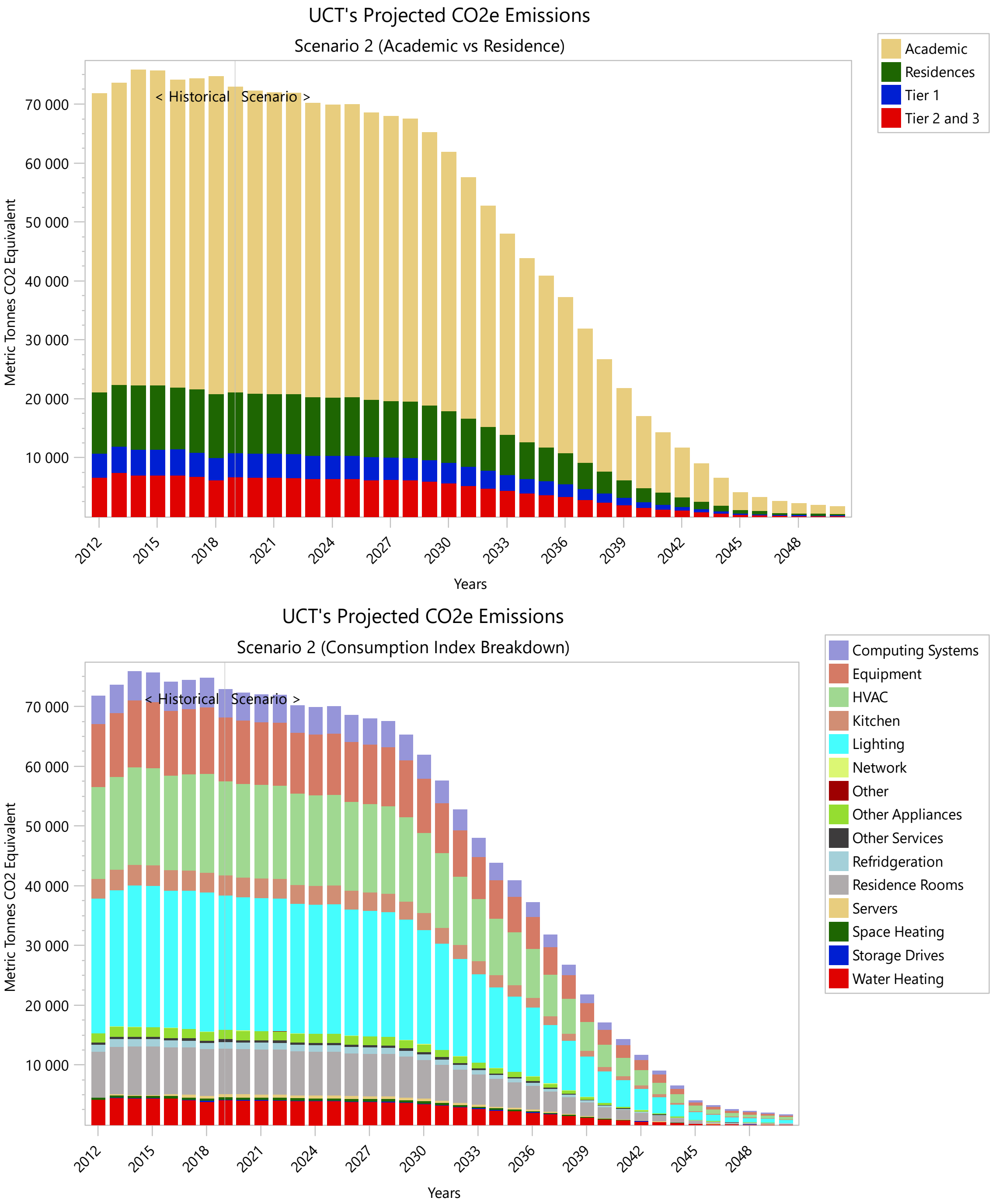


Figure 4-11: UCT's projected CO$_2$e emissions under Scenario 2 (Building Type & Energy Profile Level)

4.6 Scenario 3: Demand Side Management

4.6.1 Remaining energy demand

The final scenario in the model incorporates the demand side interventions on HVAC, Lighting Systems and Water Heating for all academic buildings, as discussed in Scenario 3: Demand Side Management in the methodology. By incorporating the percentage reductions on these energy uses outlined in Table 3-8, UCT's remaining energy demand projected into 2050 is illustrated in Figure 4-12 below:

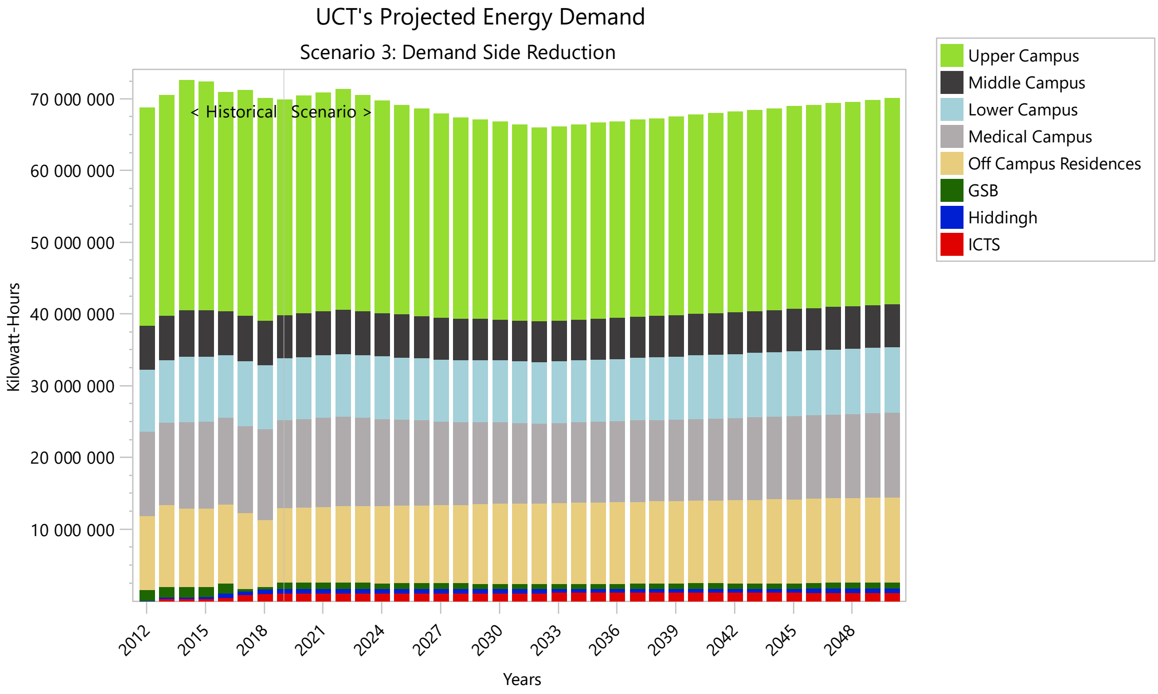


Figure 4-12: UCT's projected remaining energy demand

As can be seen in Figure 4-12, the demand side reduction measures do initially reduce UCT's total energy demand after implementation, however considering that the model was built upon the institution's energy demand increasing with an increase in the estates area, these measures reach its final reduction in 2031, before the institutions energy demand starts to increase again (based off its assumed area growth). The detailed list of reduction measures and technologies reported in the energy audit reports can be found in Appendix B1: Scenario 3 – Demand Side Management under Table 7-12.

4.6.2 Projected Scope 2 emissions

By incorporating the percentage reductions on these energy uses outlined in Table 3-8, UCT’s Scope 2 emissions are illustrated in Figure 4-13. The detailed list of reduction measures and technologies reported in the energy audit reports can be found in Appendix B1: Scenario 3 – Demand Side Management under Table 7-12.

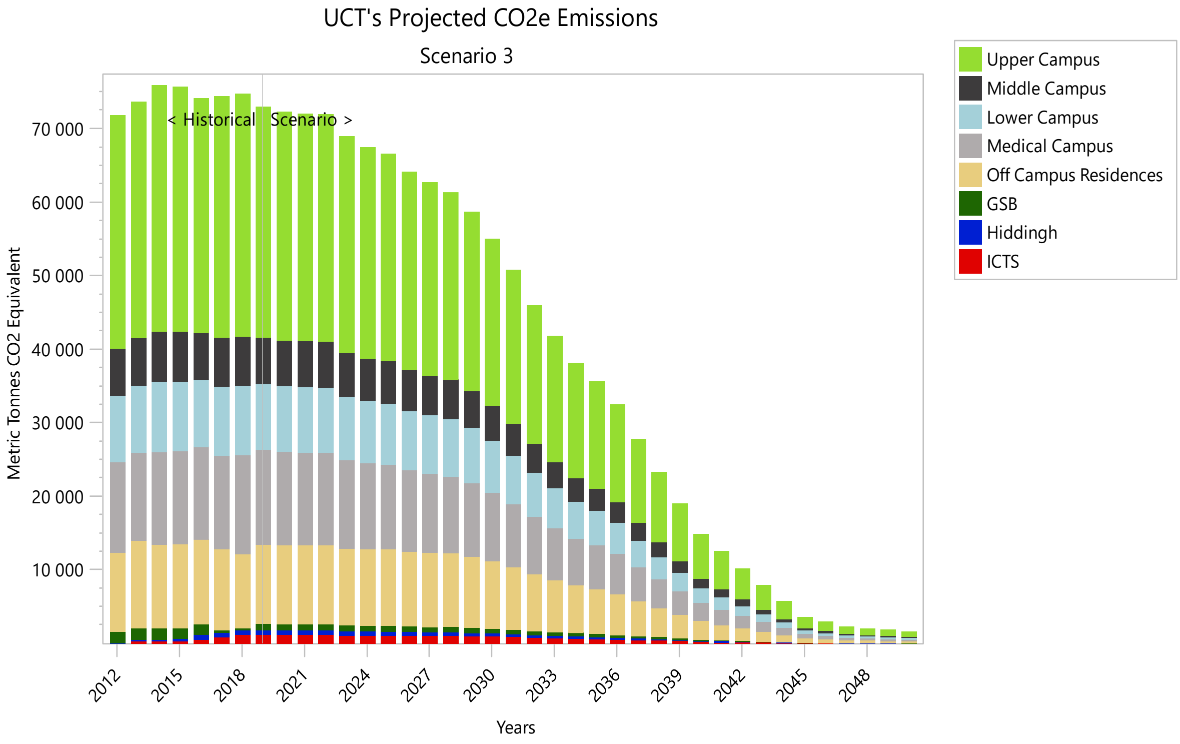


Figure 4-13: UCT's projected CO_2e emissions under Scenario 3 (Campus Level)

By implementing these demand side reduction measures in Scenario 3, UCT would produce approximately 55 079 tons per annum of CO_2e emissions in 2030, with this reducing to approximately 1 545 tons per annum of CO_2e emissions by 2050. Although an improvement from Scenario 2, under Scenario 3 the institution will only reduce its Scope 2 emissions by half between 2034 and 2035 (two years earlier than in scenario 2, and three years earlier than Scenario 1). Hence, should the university want to keep want to reduce their Scope 2 emissions by half by 2030, additional measures must be implemented to reduce their emissions at a quicker rate.

Figure 4-14 reports these emissions based on building type and by energy use.

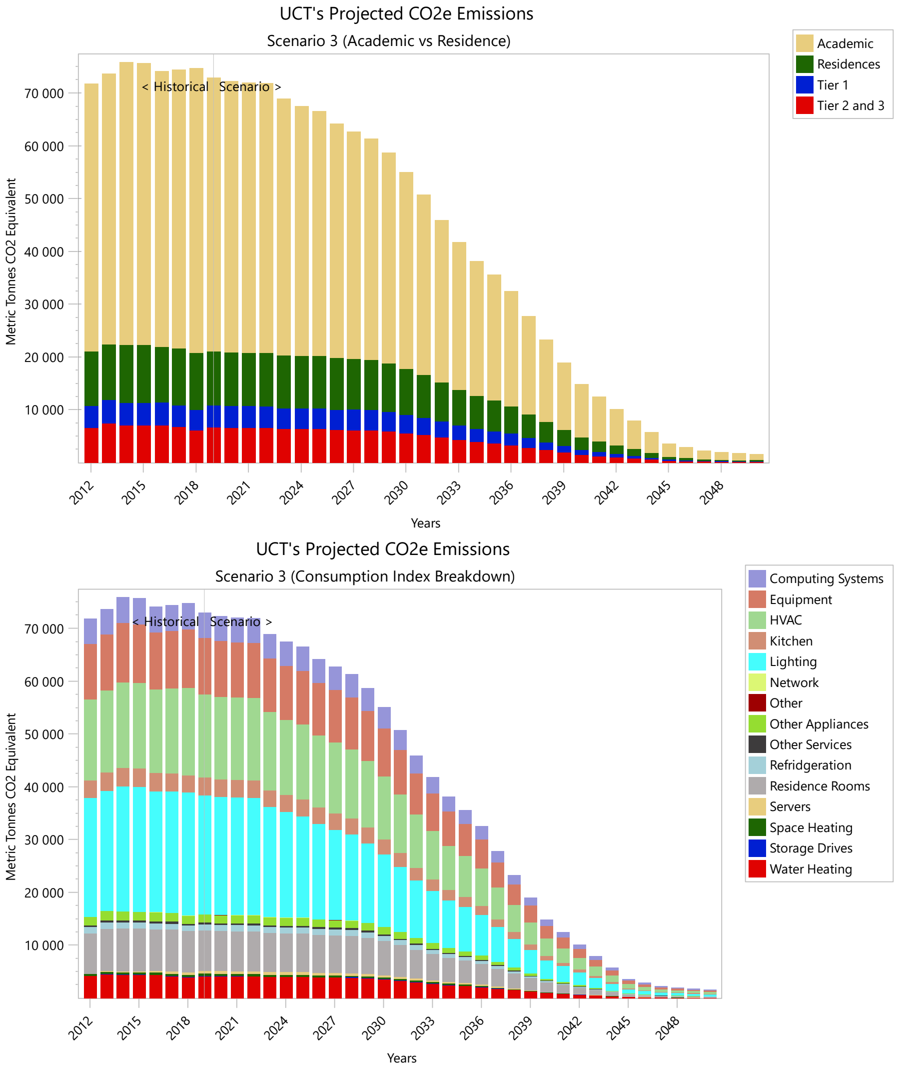


Figure 4-14: UCT's projected CO_2e emissions under Scenario 3 (Building Type & Energy Profile Level)

4.7 Comparative Analysis of Scenarios

The compare the effectiveness of the reduction methods, the institution's emissions were compared across the modelled scenarios. Table 4-11 compares the Scope 2 emissions of the modelled scenarios to the reference case. The 2019 year served as a baseline to be compared to as this was the last set of historical data (thus from 2020 onwards the scenarios produce different emissions). In the hypothetical reference case, Scope 2 emissions increase by 7.5% by 2030, and by 14.9% by 2050 (all relative to the institution's 2019 emissions). Scenario 1, which incorporates the decarbonisation of the national grid, results in the institution's Scope 2 emissions being reduced by 7.5% by 2030, and a further reduction of 91.4% by 2050 (relative to 2019 emissions). In comparison, Scenario 2, which incorporates PV into the model results in the institution's Scope 2 emissions being reduced by 15.1% by 2030, and a further reduction of 97.6% by 2050 (relative to 2019 emissions). Finally, Scenario 3, which additionally incorporates the demand side reduction measures in HVAC, Lighting and Water Heating result in the institution's Scope 2 emissions being reduced by 24.5% by 2030, and a further reduction of 97.9% by 2050 (relative to 2019 emissions).

Table 4-11: Comparison of CO_2e emissions between the modelled scenarios

Scenario	Emissions in 2019	CO_2e Emissions in 2030 (t/a)	CO_2e Emissions in 2050 (t/a)	2019 emissions reduced by half
Reference case	**72 914**	78 360	83 807	Not achieved
1	**72 914**	67 429	6 239	2037-2038
2	**72 914**	61 901	1 773	2036-2037
3	**72 914**	55 079	1 545	2034-2035

4.7.1 Best performing scenario by 2030

The effect of PV in isolation is determined by the difference in emissions reductions between Scenario 2 and Scenario 1, which is 7.6%. The effect of implementing the demand side reduction measures in isolation is determined by the difference in emissions reductions between Scenario 3 and Scenario 2, which is 9.4%. This indicates that if the demand side reduction measures were implemented in isolation of PV installation (Scenario 2) and the national grid decarbonizing (Scenario 1), it would have the greatest reduction in Scope 2 emissions, as compared to the other scenarios implemented in isolation. Thus, energy efficiency investments would be the best performing intervention in terms of emissions reduction for the 2030 timeline.

4.7.2 Best performing scenario by 2050

Unlike the 2030 timeline, the 2050 timeline allows for the national grid to decarbonize over a longer period, and thus having a greater impact on reducing the university's Scope 2 emissions. Table 4-11 reports the reduction of Scope 2 emissions by 2050, where Scenario 1 results in a significant reduction of 91.4%. The incorporation of Scenario 2 and Scenario 3 does not play as major a role in the longer timescales, and they only reduce the total emissions by a further 6.1% and 6.4% respectively, in relation to Scenario 1. Thus, the best performing scenario for the 2050 timescale would be Scenario 1, which would be the decarbonisation of the national grid. This indicates that in this model simulation, UCT would be heavily reliant on the decarbonisation on the national grid to significantly reduce its Scope 2 emissions.

4.8 Implementation Costs

Although this dissertation did not include a detailed cost analysis, it is able to present the associated cost of implementing the outlined emissions reductions measures. In Scenario 1, where UCT's energy demand remains at current trends and where no reduction methods are implemented, there would be no associated implementation costs as this scenario presents a case where the national grid decarbonizes corresponding to a 2^{o}C warming scenario, which would effectively carry no cost to UCT.

Corresponding to Scenario 2 and based on the UCT Feasibility study conducted by Arup (Pty) Ltd, installing a 2547 kWp PV system across the UCT estate would require a capital investment of R34 million and an annual operating cost of R1.2 million – where the average return on investment was reported at 3.86%, with an average payback period of 7.8 years (detailed results can be found in Table 3-6). It should be noted that this cost analysis was performed by Arup (Pty) Ltd and not by any cost analysis conducted in this dissertation.

Scenario 3 represents the demand side interventions on HVAC, Lighting and Water Heating on all academic type buildings. SEM Solutions found that implementing these measures on just the 16 buildings audited would cost R39.9 million, with a total estimated annual savings of R6.6 million with an average payback period of 6.6 years (Table 7-12). Given that the total number of applicable buildings on the campus being 104, and assuming that these intervention measures could be applied to all of these buildings, it would cost the institution approximately R260 million. It should be noted that this is indeed an overestimation of implementation measures, as it is unlikely that the remaining buildings would require these exact same implementations. Older buildings would be eligible for significantly more upgrades, while newer buildings on the campus may require very little to no intervention at all. It should also be noted that the interventions considered are for HVAC, Lighting and Water Heating, thus there lies a great potential in introducing reduction measures on other significant energy uses (like equipment and computing systems).

5 CHAPTER FIVE: CONCLUSIONS AND RECOMMENDATIONS

This chapter of the dissertation reports the final conclusions and recommendations of the study.

5.1 Stakeholder engagements

5.1.1 Conclusions

One of the key research questions posed in this dissertation were the potential insights gained through stakeholder engagement and if these insights were transferrable into constructing an energy systems model to inform policy around decarbonizing the university.

Other than sourcing emissions and high-level electricity consumption data made available from the UCT Carbon Footprint reports, much of the data that was utilized in constructing the LEAP model (from its key assumptions to its scenario analysis), was obtained through engaging with various members of UCT's academic, managerial, and operational staff.

Through engaging with different level of UCT's operational, managerial, and academic staff, this dissertation has highlighted that campus sustainability at the institution has become more organized and cohesive since the Vice Chancellor appointed a Director for Environmental Sustainability at the institution. This increased co-ordination of campus sustainability projects has led to two energy audits being conducted on the University (one in 2017 and one in 2019), which have provided insights into the energy profiles of the types of buildings present on campus, and what energy efficiency retrofits can be implemented in order to decrease the electricity demand of these buildings (see Table 7-12: Summary of demand side interventions from the energy audit reports conducted by SEM Solutions found in Appendix B1: Scenario 3 – Demand Side Management). In engaging with the Director for Environmental Sustainability, these reports were made available for assessment in this dissertation, indicating that because of this particular engagement, this insight was directly transferable into the construction of the LEAP model. This generated data from the energy audits has proven to be of great significance to UCT in distinguishing the institution's electricity consumption profiles. The results of these energy audits had served as a foundation upon which the LEAP model was constructed.

A further engagement with the Director for Environmental Sustainability and other members of academic staff had uncovered UCT's Solar Photovoltaic project. The results of this study were directly transferrable into the construction of the LEAP model. The effectiveness of this particular project, as well as the use of the data from the energy audits will be discussed later in this chapter.

Qualitatively, UCT has shown tangible commitments towards campus sustainability by uniting the different levels of management and governance on the campus was the creation of the Khusela Ikamva Initiative. At this point of the initiative however, it is still too early to assess the overall success and impact of the project. Indeed, it has made progress in connecting various departments within the UCT community through its active sub-projects (as shown in Figure 4-1). The budget alone for the initiative has already shown the institutions dedicated commitment towards sustainability that it has lacked in the past.

5.1.2 Recommendations:

Although stakeholder engagement was crucial in sourcing the data upon which the LEAP model was constructed, the study did not engage extensively with the student community at the institution. Thus, future research should include representatives of the student population (such as the Green Campus Initiative) to provide their insights on what campus sustainability means to them, and the active roles they can embody. The student community accounts for the majority of the UCT population, and thus their voices should be at the forefront of campus sustainability. One such measure to consider to improve the model would be to incorporate the effect of behavioural change on campus and how this can reduce the electricity demand on the estate – a scenario in which students would be the main factor.

5.2 Disaggregation of the UCT estate

5.2.1 Conclusions

A key research question posed in this dissertation was to determine the level of disaggregation of energy data that would provide decision makers new insights.

Based on the Carbon Footprint Reports, the disaggregation of electricity data was reported at the campus level. Indeed, decision makers could determine which campuses were the main electricity consumer, however not much insight was provided on the types of buildings that consume the most electricity, and the subsequent operations that consume the most electricity at these buildings.

This dissertation has illustrated these two insights by disaggregating the electricity consumption data into building types (academic vs residences) as well as establishing the electricity consumption profiles of these types of buildings. During the period of 2012 to 2019, academic type buildings were responsible for approximately 70% of the total electricity consumption of the UCT estate, with Tier 1 residences accounting for 15% of the total electricity consumption, and Tier 2 and Tier 3 accounting for the remainder (Figure 4-4). Based on this, for UCT to significantly reduce their energy demand and its associated carbon footprint, the institution will have to target their sustainability plans to academic type buildings.

A further insight from the LEAP model was disaggregating the UCT estate into energy profiles. During the period of 2012 to 2019, the main uses of electricity were attributed to lighting, HVAC, and equipment, which were (on average) responsible for 31%, 21% and 15% of the total electricity consumption on the UCT estate (Figure 4-4). Based on this, for UCT to significantly reduce their energy demand and its associated carbon footprint, the institution will have to target their sustainability plans to address lighting, HVAC and equipment used on the UCT estate. This could further be interpreted that these services are operating inefficiently, and thus there lies potential in reducing the institutions electricity demand by upgrading these technologies. It cannot be concluded that lighting is inefficient solely because it uses 31% of the institution’s electricity demand on average. However, the energy audit reports do conclude that there exists an enormous savings potential for lighting, HVAC and for equipment used by the university. Thus, based on this assessment, as well as the findings from the energy audit reports, it can be concluded that the university is lagging on energy efficiency in its academic buildings.

5.2.2 Recommendations

The types of buildings, as well as the institution’s energy profile, with regards to electricity consumption, can provide decision makers insight into where they should target their efforts in reducing the institution’s emissions. In order to improve on the information of the types of buildings that consume the most electricity on the campus (either academic or residence), future research should utilize sub-meter data for individual building types to attain a more accurate depiction. The current LEAP model assumed that electricity consumption and area were inherently linked - in that area ratios could be applied to electricity consumption however in reality this relationship is not so linear. Thus, to improve the disaggregation of electricity consumption data, sub-meter data per building type should be utilized to provide a more accurate picture of the electricity consumption of these building types (sub-meter data was not available at the time of this study). A potential recommendation to UCT itself would be to install sub-meters per building (or at least sample buildings) in order to support this conclusion.

In terms of UCT's energy profile, the LEAP model utilized 16 energy audits of different buildings on the institution, 15 of which were for academic type buildings. To improve upon this, future research should incorporate conducting energy audits on more residence type buildings to create a larger sample size, and reflect the institution's energy use profile more accurately, as this study only made use of one energy audit report to model the energy profile of residence type buildings on the campus.

5.3 Level of accuracy of the LEAP model

5.3.1 Conclusions

A key research question of this dissertation was to determine to what degree of accuracy the LEAP model simulates historical data.

The modelled historical baseline (Figure 4-4) serves as a control on which to compare UCT's actual historical consumption (Table 2-2) during the same time period. The modelled historical baseline results were compared to UCT's actual historical energy consumption for the same time period. In comparing these two sets of data Figure 5-1 illustrates the percentage difference between the actual historical energy consumption to the modelled historical energy consumption. As can be seen, the percentage difference increases over time, at a rate of 0.6% per year. One possible explanation is that the baseline model does not include energy efficiency improvements that occurred during this period. Such improvements would be plausible, given the significant rise in electricity costs during this period, which would have triggered institutional responses. An implication of the omission of such ongoing energy efficiency improvements in the model setup would be that future energy demand predictions are too high, and over 30 years this could be by as much as 22% (4% + 18%) in 2050.

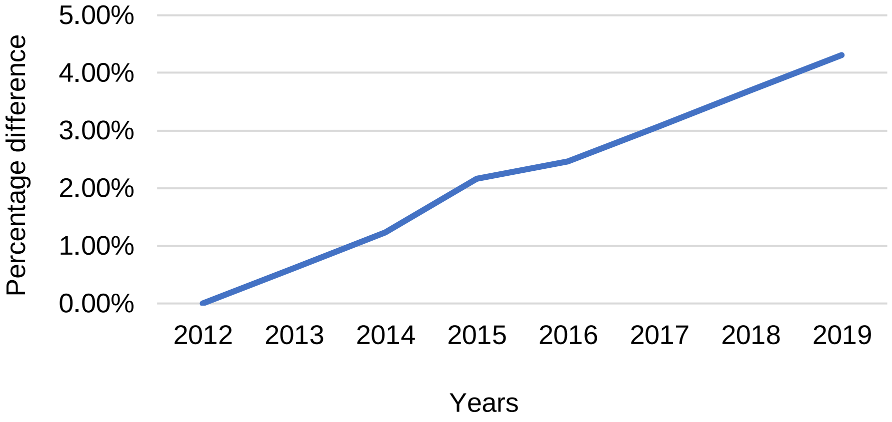


Figure 5-1: Graph showing the percentage difference in UCT's modelled energy consumption vs its historical energy consumption

5.3.2 Recommendations

The reason for the error difference is rooted in the assumptions that the model utilized in producing the reference case, specifically the assumptions made about the area expansion of the campus. The model utilized historical area for 2012, explaining why there was no difference in the energy consumption between the two sets of data. However, the model made use of area expansion assumptions outlined in the methodology section of this dissertation. The model was simulated to represent the institution’s energy consumption as a factor of its area (kWh/m^2), thus any growth in area of the institution would result in a growth in the energy demand of the institution. Hence, the percentage difference in energy consumption between these two data sets is a result of these growth assumptions. It is important to draw comparison to the carbon footprint reporting, which indicates that energy efficiency had generally improved during this period, and specifically that the area-specific energy demand (kWh/m^2) had declined (UCT Carbon Footprint Report, 2019). This improvement in energy efficiency was not captured into the baseline (as the model intended to focus on future energy efficiency measures). Thus, future work on the LEAP model will need to capture these historical energy efficiency measures, otherwise the predicted energy demand will be too high, and growing, into the future. In this case, it is recommended that future modelling work include past and ongoing energy efficiency gains in the baseline.

5.4 Impact of scenario analysis on informing emissions reduction policy

5.4.1 Conclusions

A key research question of this dissertation was to determine how useful energy systems models are in providing insights into emissions reduction strategies and to further determine which of the type of interventions (supply side vs demand side) have a greater impact on reducing UCT's carbon footprint, considering the institution's current plans. UCT had declared ambitious goals to reduce their carbon footprint by half by 2030 (relative to its 2019 emissions) and to achieve net-zero by 2050.

With UCT's current proposed and suggested plans of implementing all three scenarios, the institution fails to reduce its emissions by half by 2030 (Table 4-11). Implementing all three scenarios' results in this only being achieved between 2034 and 2035, however, this still only considers Scope 2 emissions and does not account for Scope 1 or Scope 3 emissions. In the 2050 timeline, implementing all three scenarios reduces its Scope 2 emissions by 97.9% (Table 4-11) which could be considered an achievement of the institution's commitments. However, an important factor to note here is that this emissions reduction is largely attributed the national grid decarbonizing, dwarfing UCT's own efforts of reducing its emissions. As it stands, the institution relies heavily on the national grid decarbonizing in reaching its own reduction goals.

Although this may seem like a failure on the institution's part, it provides valuable insight into how policy needs to ramp up sustainability efforts on campus and across the institution. The results of the LEAP model demonstrate that UCT's current sustainability plans are not nearly enough to achieve their set out goals, as with the proposed current plans, the institution does not zero out its Scope 2 emissions. These results should be an indicator to decision makers to ramp up sustainability efforts and introduce policy that allows for the funding and execution of more interventions that reduce energy demand, as well as looking into alternative energy sources to compensate the institutions energy supply. This is significant, as the proposed plans (especially those on the demand side) are all currently hypotheticals. Should UCT want to uphold their sustainability commitments, they will have to invest in many more, extensive sustainability projects. Suggestions of these types of interventions can be in investigating the feasibility of building a much larger scale solar PV plant that would provide the institution with clean, sustainable, and renewable energy (thus lowering its emissions), or alternatively sourcing clean energy from independent power producers (IPPs).

Another conclusion on this aspect is the effectiveness of establishing living labs on campus. The currently planned solar PV installation (that could also serve as a living lab on the campus) would only reduce the institution's Scope 2 emissions by 7.6%. Although this may seem like a small impact in terms of emissions reduction, one cannot write this off as a failure or as being ineffective yet (as more PV installations might be possible). Additionally, living labs serve to teach by demonstration, and much of its success lies in that, thus there lies a social aspect and impact that the establishment of a visible campus sustainability project can have on the UCT community. Thus, it is still too early to make provide a decisive conclusion on the success or effectiveness of establishing living labs on the UCT campus.

Considering the three scenarios, it can be concluded that the window for UCT to implement its own emissions reduction strategies is short-term, as much of the expected emissions reduction post 2030 is from measures not implemented by the institution itself. Comparing the reduction of emissions from Scenario 1 vs Scenario 2 and 3, it is clear that Scenario 1 is responsible for most of UCT's reduction in emissions post 2030.

5.4.2 Recommendations

Based on the insights gained from the LEAP model about UCT's known sustainability plans, it is recommended that future modelling work or research should undergo a more comprehensive assessment of the institution's sustainability and/or maintenance plans. Although energy audit reports were used to model demand side interventions, the model did not consider the already planned and scheduled maintenance plans of the institution's infrastructure. The inclusion of this could see the institution's energy demand decreasing at a greater rate than what is currently modelled.

Additionally, in noting that most of UCT's emissions reductions post 2030 are from measures not implemented by the institution itself, it is recommended that UCT recognize that the window for meaningful own action is short-term. Thus, in order for the institution to live up to its sustainability commitments, in that a university should be leading, and not lagging society, it needs to take significantly more action in the short term regarding its emissions reduction plans.

5.5 Implementation costs

5.5.1 Conclusions

A key research question of this dissertation was to determine the associated implementation costs of these emissions' reduction strategies presented.

For Scenario 2, implementing a 2547 kWp PV system across the UCT estate would require a capital investment of R34 million and an annual operating cost of R1.2 million (detailed results can be found in Table 3-6). For Scenario 3, implementing demand side interventions on HVAC, Lighting and Water Heating on all applicable buildings on the UCT estate would cost the institution approximately R260 million.

These implementation costs reported are a rough estimation, as it is unlikely that the remaining buildings would require these exact same implementations. Different types of buildings would require different types of interventions (older buildings would need significantly more upgrades, while newer buildings may require very little to no intervention at all).

5.5.2 Recommendations:

Firstly, it should be noted that although there are estimated costing conclusions provided, this study did not conduct a detailed costing analysis, where it instead focused heavily on the institution's emissions reduction options from a supply and demand side. It is recommended that future research work carry out a detailed costing analysis on these types of implementations and introduce a cost-benefit scenario that assess the viability of some of the intervention options.

It should also be noted that the interventions considered are for HVAC, Lighting and Water Heating, thus future research should investigate the potential of introducing reduction measures on the institution's other significant energy uses (like equipment and computing systems).

5.6 Additional Recommendations

It is clear that with the current proposed sustainability plans and with the national grid decarbonizing, UCT still falls short of meeting its 2030 and 2050 commitments. Thus, the following recommendations are suggested for future research into providing the institution with additional emissions reduction options:

1. Investigate purchasing electricity, generated from renewable resources, from Independent Power Producers to offset the institution's carbon footprint.
2. Carry out more energy audits on previously unaudited buildings to improve the sample sizes that would determine the institution's energy profile.
3. Assess the impact of collaborating with the dominant population on the campus (being the student population), and to assess the role that they can play in reducing the institution's electricity use and thus emissions. This could be from an operational and/or behavioral perspective.
4. Expand the scope of the study to incorporate Scope 1 emissions first, and then once well established, to then incorporate Scope 3 emissions.

Reducing the carbon footprint of an institution requires a holistic approach involving stakeholder engagement and the use of energy systems models. Stakeholder engagement is crucial for understanding diverse perspectives, building support, and incorporating expertise. It enhances credibility, ensures regulatory compliance, and involves the community in sustainability initiatives. Energy systems models provide a data-driven framework for decision-making by analyzing energy consumption patterns, facilitating scenario planning, optimizing resource allocation, quantifying impact, and conducting cost-benefit analyses. The combination of these elements enables institutions to develop effective, transparent, and sustainable strategies aligned with stakeholder interests.

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7 APPENDICES

7.1 Appendix A: Campus Area’s and Energy Profiles

This section of the dissertation provides the latest list of buildings on each campus with their respective areas. The areas of these buildings were used to determine the split between academic type buildings and residence type buildings. It was assumed that the split in area between academic and residence type buildings would equate to the split in total energy consumption. Additionally, the data required for the determination of each energy profile for each UCT campus can be found in this section of the dissertation.

7.1.1 Appendix A1: Upper Campus

The energy profiles of Upper Campus were included in the main body of this report as sample calculations and can be found under 3.3 Calibration of UCT’s Electricity Consumption and Energy Profile in Table 3-4. Table 7-1 below showcases the full list of buildings on Upper Campus and their associated areas which were used to establish area ratios between Academic vs Residence type buildings, which would ultimately be used to determine the energy consumption of these building types.

Table 7-1: Upper Campus building areas

Building Name	Ext. Gross Area m²	Int. Gross Area m²
Snape Lecture Theatres Building	736.42	673.28
Environmental & Geographical Science Building	3 404.58	3 227.44
Hoerikwaggo	3 239.68	2 944.21
PD Hahn Building	19 744.72	17 469.16
Neville Alexander Building	7 211.86	5 209.98
Geological Sciences Building	3 859.42	3 385.84
Elect. & Mech. Eng. Building	6 058.30	5 028.10
Computer Science Building	5 780.79	4 989.07
Leslie Social Science Blg	20 990.23	16 230.97
Centlivres Building	9 357.40	7 785.78
A.C. Jordan Building	5 112.68	4 424.16
Maths Building	6 722.21	5 175.40
RW James Building	9 539.05	6 902.86
Fuller Hall	15 703.80	8 172.40
Smuts Hall	15 816.28	8 218.50
Geological Science Ext Building	1 232.39	1 084.78
G.H. Menzies Building	14 373.32	12 614.91
John Day Building	9 478.33	8 194.07
Molecular Biology Building	17 056.58	15 550.74

Leslie Commerce Building	9 500.29	8 071.96
Maintenance Building	3 258.75	2 955.59
Sports Centre	14 817.57	13 820.79
Beattie Building	8 227.25	7 466.35
J.W. Jagger Library	8 022.53	7 253.39
Tennis Club House	525.00	0.00
Harry Oppenheimer Institute	1 670.75	1 499.27
Students Union Extension	6 194.56	5 664.64
Immelman Building	6 016.72	5 576.08
H.W. Pearson Building	5 900.13	4 971.52
Chemical Engineering Building	9 025.51	8 217.92
New Engineering Building	12 759.70	8 392.96
Snape Building	4 170.00	0.00
New Lecture Theatre	2 843.69	2 564.80
Steve Biko Students Union	3 708.01	3 334.47
Chris Hani	2 276.18	1 997.47
Jameson Hall	2 067.34	1 804.05
Otto Beit Building	2 025.12	1 778.29
Rachel Bloch House	804.34	721.45
Educare Centre	560.75	499.98
Nursery	476.00	432.50
Greenhouse	315.98	296.65
Gas Store	216.58	177.04
Animal House	196.08	160.10
Botany Glass House	125.04	115.07
Engineering Greenhouse	127.80	106.45
Information Centre	102.28	96.56
Earth Dam Pump House	0.00	0.00
Total Area	281 351.99	225 257.00

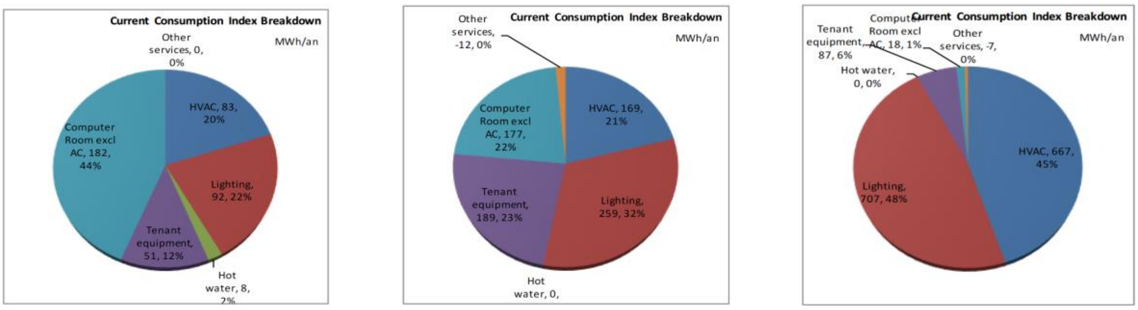
7.1.2 Appendix A2: Middle Campus

Table 7-2 below showcases the full list of buildings on Upper Campus and their associated areas which were used to establish area ratios between Academic vs Residence type buildings, which would ultimately be used to determine the energy consumption of these building types.

Table 7-2: Middle Campus building areas

Building Name	Ext. Gross Area m²	Int. Gross Area m²
Wilfred and Jules Kramer	19 330.43	17 883.60
The School of Economics Building	9 254.64	7 478.29
Woolsack Pavilions	4 311.30	3 313.24
Woolsack Courts	3 239.84	2 647.70
The Woolsack	965.07	775.01
Woolsack Colonnade - NEW	745.30	594.68
Cricket Pavilion	433.27	379.32
Summer House	63.31	47.16
Bremner Building	4 396.36	3 779.16
Welgelegen	701.81	582.65
Squash Courts	550.00	0.00
All Africa House	4 090.02	3 675.79
Masingene	3 405.05	3 077.66
Kopano Residence	5 500.00	0.00
Welgelegen Gateway(Soccor Field)	0.00	0.00
Total Area	**56 986.40**	44 234.26

Figure 7-1 showcases the buildings that were assessed on Middle Campus along with their associated energy profiles determined by SEM Solutions.



Bremner

School of Economics

Kramer

Figure 7-1: Energy Profiles from energy audits conducted by SEM Solutions of buildings on Middle Campus

Table 7-3 below reports the buildings that were assessed on Middle Campus along with their associated energy profiles determined by SEM Solutions.

Table 7-3: Energy Profiles from energy audits conducted by SEM Solutions of buildings on Middle Campus[1]

Energy Audit Reports (2019)	**Bremner**	**Energy Use**	**HVAC**	**Lighting Systems**	**Equipment**	**Computing Systems**	**Water Heating**
		Consumption Energy Index Breakdown	20%	22%	12%	44%	2%
		416 555	83 311	91 642	49 987	183 284	8 331
	School of Economics	**Energy Use**	**HVAC**	**Lighting Systems**	**Equipment**	**Computing Systems**	
		Consumption Energy Index Breakdown	23%	32%	23%	22%	
		781 483	179 741	250 075	179 741	171 926	
	Kramer	**Energy Use**	**HVAC**	**Lighting Systems**	**Equipment**	**Computing Systems**	
		Consumption Energy Index Breakdown	45%	48%	6%	1%	
		1 471 978	662 390	706 549	88 319	14 720	

[1] Consumption energy index breakdown indicates the percentage of the energy use type as well as the corresponding energy consumption of that energy use (kWh)

7.1.3 Appendix A3: Lower Campus

Table 7-4 below showcases the full list of buildings on Lower Campus and their associated areas which were used to establish area ratios between Academic vs Residence type buildings, which would ultimately be used to determine the energy consumption of these building types.

Table 7-4: Lower Campus building areas

Building Name	Ext. Gross Area m²	Int. Gross Area m²
Graca Machel Hall	18 042.44	17 689.66
Baxter Theatre	17 008.13	15 269.10
New College of Music	5 389.99	4 805.65
Ballet School	1 678.05	1 509.98
Strubenholm (Col of Music	1 579.19	1 281.14
Old Admin Building	780.35	632.54
Baxter Hall	7 630.00	0.00
Burnage	452.20	410.04
Isaac Albow Building	708.24	618.74
Tugwell Hall	11 699.23	9 172.57
Leo Marquard Hall	10 921.24	9 142.08
New Gym & Change Rooms	868.29	804.84
LC Student Learning Centre	751.86	696.64
Research & Innovate House	605.47	508.58
Ablution Block (Tug&Marq)	482.58	409.26
The Cottage	308.82	264.25
Scuba Club	221.44	198.39
C Sharp Cottage	215.60	169.16
Jammie Shuttle Terminus	159.22	139.23
Upalong - Ballet Wardrobe	139.33	105.29
Ballet Classroom	116.55	105.06
Glenara	827.00	0.00
Common Room (The Cottage)	0.00	0.00
Total Area	**80 585.22**	**63 932.20**

7.1.4 Appendix A4: Medical Campus

Table 7-5 below showcases the full list of buildings on Medical Campus and their associated areas which were used to establish area ratios between Academic vs Residence type buildings, which would ultimately be used to determine the energy consumption of these building types.

Table 7-5: Medical Campus building areas

Building Name	Ext. Gross Area m²	Int. Gross Area m²
Falmouth Building	9 442.42	8 205.12
Wernher & Beit South	7 159.62	6 244.74
Wernher & Beit North	5 164.23	4 370.18
Medical Residence	4 467.99	3 724.05
Medical Library	4 056.58	3 582.33
Anatomy Building	10 680.99	9 310.88
Maintenance Workshop Building	265.48	228.60
Wolfson Pavilion	1 721.97	1 555.29
Barnard Fuller	4 932.18	4 372.33
Chris Barnard Building	6 839.01	5 775.82
Mortuary Building	812.14	686.57
Animal House	579.65	492.64
Braemar Cottage	182.76	157.47
Lung Institute, Boehringer Ingelheim	2 518.30	0.00
Total Area	**58 823.32**	**48 706.02**

Figure 7-2 showcases the buildings that were assessed on Middle Campus along with their associated energy profiles determined by SEM Solutions.

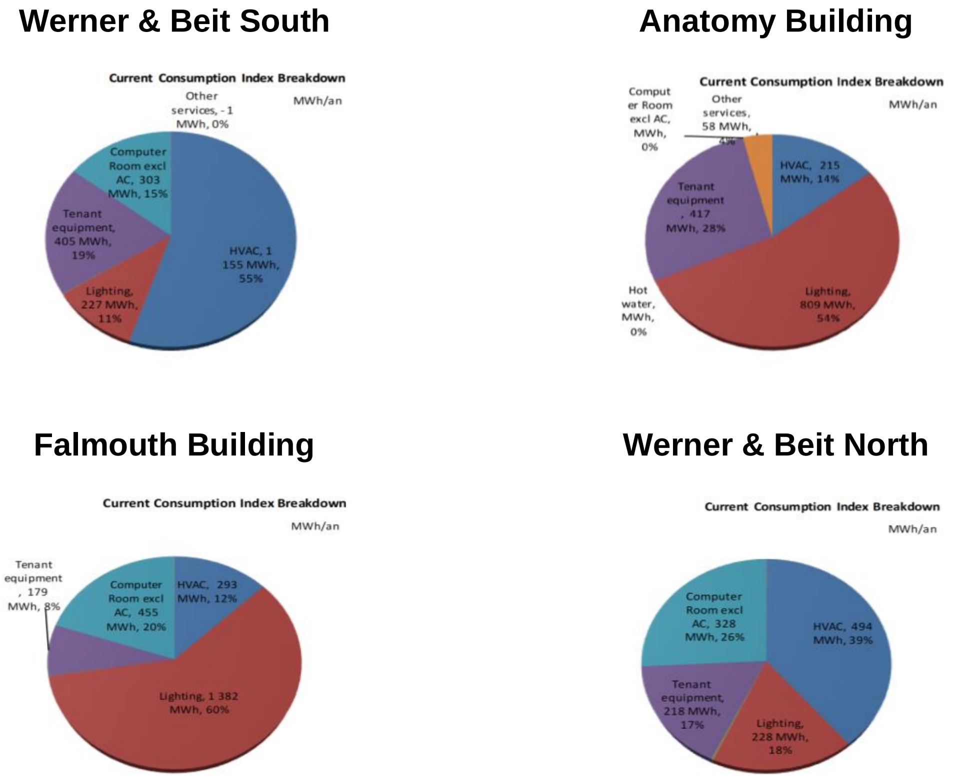


Figure 7-2: Energy Profiles from energy audits conducted by SEM Solutions of buildings on Medical Campus

Table 7-6 below reports the buildings that were assessed on Medical Campus along with their associated energy profiles determined by SEM Solutions.

Table 7-6: Energy Profiles from energy audits conducted by SEM Solutions of buildings on Medical Campus[1]

Energy Audit Reports (2019)	**Wernher & Beit South**	**Energy Use**	**HVAC**	**Lighting Systems**	**Equipment**	**Computer Rooms**
		Consumption Energy Index Breakdown	55%	11%	19%	15%
		2 090 613	1 149 837	229 967	397 216	313 592
	Anatomy	**Energy Use**	**HVAC**	**Lighting Systems**	**Equipment**	**Other Services**
		Consumption Energy Index Breakdown	14%	54%	28%	4%
		1 499 797	209 972	809 890	419 943	59 992
	Falmouth	**Energy Use**	**HVAC**	**Lighting Systems**	**Equipment**	**Computer Rooms**
		Consumption Energy Index Breakdown	12%	60%	8%	20%
		2 310 154	277 218	1 386 092	184 812	462 031
	Wernher & Beith North	**Energy Use**	**HVAC**	**Lighting Systems**	**Equipment**	**Computer Rooms**
		Consumption Energy Index Breakdown	39%	18%	17%	26%
		1 270 917	495 658	228 765	216 056	330 438

[1] Consumption energy index breakdown indicates the percentage of the energy use type as well as the corresponding energy consumption of that energy use (kWh)

7.1.5 Appendix A5: ICTS on Main

Table 7-7 below showcases the full list of buildings on for ICTS on Main and their associated areas – this facility was assumed to be entirely Academic type buildings.

Table 7-7: ICTS on Main building areas

Building Name	Ext. Gross Area m²	Int. Gross Area m²
ICTS On Main	3 634.59	2 878.07
Total Area	3 634.59	2 878.07

Figure 7-3 shows the typical energy profile of data centers by end use.

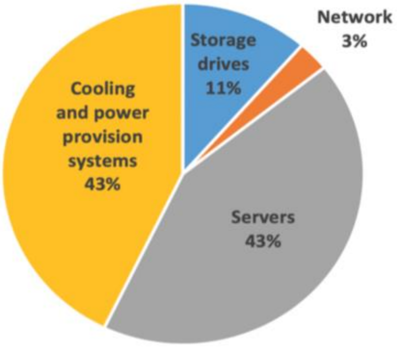


Figure 7-3: Typical energy profiles of data centre electricity use (Shehabi, 2016)

7.1.6 Appendix A6: Off Campus Residences

Table 7-8 below showcases the full list of buildings on for ICTS on Main and their associated areas – this facility was assumed to be entirely Residence type buildings.

Table 7-8: Off Campus Residences building areas

Building Name	Ext. Gross Area m²	Int. Gross Area m²
Obz Square	29 066.68	25 950.70
Liesbeeck Gardens	36 206.64	18 488.37
Meulenhof Building	4 188.39	3 772.96
Dullah Omar Hall	3 278.93	2 844.58
Ivan Toms Building	1 750.09	1 194.17
Forest Hill Muelenhof	960.00	883.94
Avenue House	1 114.47	871.64
Kilindini	892.22	698.96
Linkoping	680.39	544.65
Cadbol Building	647.09	534.99
U H E Block	524.16	459.08
U H Dining Room	516.94	439.91
U H D Block	482.11	421.21
U H C Block	482.11	421.00

U H B Block	482.11	421.00
U H A Block	476.48	418.67
U H Wardens House	318.50	276.95
U H Cottages 1 & 2	157.65	139.72
U H Cottages 3 & 4	157.84	137.99
U H Cottages 5 & 6	151.46	132.01
U H Surgery	24.51	17.95
U H Garage	17.71	13.89
College House	3 392.00	0.00
Inglewood	165.00	0.00
Wolmunster	679.00	0.00
U H House 4	161.00	0.00
U H G Block	480.00	0.00
Glenres (Glendower)	5 121.00	0.00
Exair	0.00	0.00
Rochester House Residence	7 000.00	0.00
Amalinda	0.00	0.00
Groote Schuur mansions (Hotel)	5 740.00	0.00
J.P.Duminy Court	3 729.00	0.00
Carinus Residence	8 000.00	0.00
Clarendon	2 529.00	0.00
Forest Hill Flats Block A	2 529.00	0.00
Forest Hill Flats Block B	2 529.00	0.00
Forest Hill Flats Block C	2 529.00	0.00
Forest Hill Flats Block D	2 529.00	0.00
Forest Hill Flats Block E	2 529.00	0.00
Forest Hill Flats Block F	2 529.00	0.00
Forest Hill Flats Block G	2 529.00	0.00
Varietas Residence	2 529.00	0.00
Total Area	**139 804.48**	**59 084.34**

Figure 7-4 showcases the buildings that were assessed on Off Campus Residences along with their associated energy profiles determined by SEM Solutions.

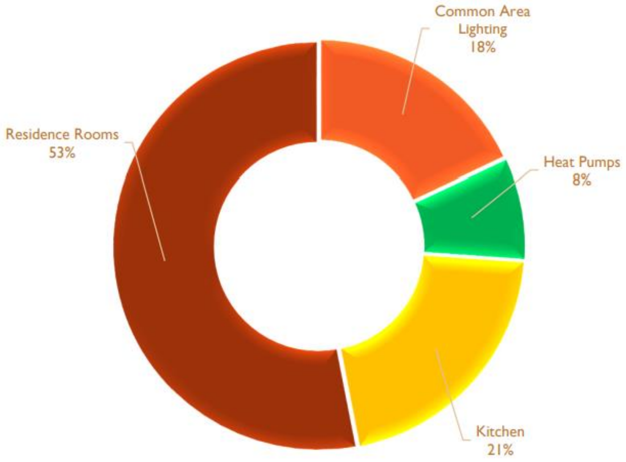


Figure 7-4: Energy Profiles from energy audits conducted by Terra Firma Solutions of buildings on Off Campus Residences

7.1.7 Appendix A7: Graduate School of Business (GSB)

Table 7-9 below showcases the full list of buildings on for ICTS on Main and their associated areas – this facility was assumed to be entirely Academic type buildings.

Table 7-9: GSB building areas

Building Name	Ext. Gross Area m²	Int. Gross Area m²
GSB Block B & D	17 088.67	15 230.19
GSB Block A	5 651.55	4 067.59
GSB Block C	2 084.77	1 787.73
Total Area	**24 824.99**	**21 085.51**

Figure 7-5 showcases the buildings that were assessed on GSB Campus along with their associated energy profiles determined by SEM Solutions.

GSB Block B & D

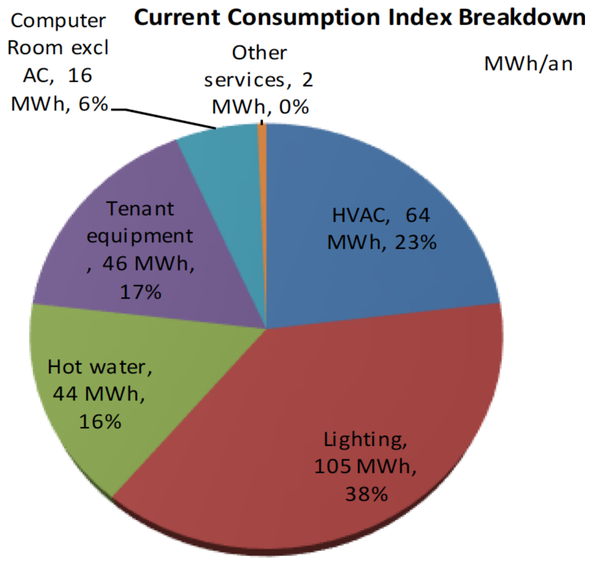


Figure 7-5: Energy Profiles from energy audits conducted by SEM Solutions of buildings on GSB

7.1.8 Appendix A7: Hiddingh Campus

Table 7-10 below showcases the full list of buildings on for ICTS on Main and their associated areas – this facility was assumed to be entirely Academic type buildings.

Table 7-10: Hiddingh Campus building areas

Building Name	Ext. Gross Area m²	Int. Gross Area m²
Ritchie Building	5 068.70	4 703.39
Rosedale Building	2 152.38	1 794.72
Hiddingh Hall	2 019.37	1 673.50
Commerce Building	1 879.62	1 622.93
Michaelis Building	1 907.72	1 566.25
Old Medical School	1 880.47	1 523.77
Little Theatre Workshop Extension Building	1 271.49	1 137.46
Little Theatre	1 355.70	1 128.71
Little Theatre Workshop	1 193.90	1 020.29
Quad Building	924.87	771.49
Egyptian Building	641.16	539.46
Graphic Design Building	593.93	511.94
Bertram Place	532.80	424.39
Total Area	21 422.11	18 418.30

7.2 Appendix B: Scenario Analysis Data

7.2.1 Appendix B1: Scenario 1 – Decarbonization of the National Grid

Table 7-11 reports the National grid electricity supply matrix generated by the ESRG at UCT under a 2ºC warming scenario. This data was used to establish the ratios of the electricity supply matrix from fuel source types in Table 3-5.

Table 7-11: National Grid electricity generation supply matrix under a 2ºC warming scenario taken from the SATIM model from the ESRG at UCT (TWh)

Fuel type used in Electricity Generation	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**
Coal Bituminous	209.54	209.54	209.54	209.54	209.54	209.54	212.56	203.63	192.49	192.45	191.31
Natural Gas	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Hydro	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70
Nuclear	15.09	15.09	15.09	15.09	15.09	15.09	10.54	13.57	13.71	13.52	11.46
Diesel	0.48	0.48	0.48	0.48	0.48	0.48	0.48	0.48	0.48	0.48	0.48
Solar	4.04	4.04	4.04	4.04	4.04	4.04	4.04	4.91	5.80	7.24	8.22
Wind	6.18	6.18	6.18	6.18	6.18	6.18	6.18	6.59	7.39	8.38	11.10
Total	236.02	236.02	236.02	236.02	236.02	236.02	234.49	229.89	220.58	222.77	223.27
Fuel type used in Electricity Generation	**2023**	**2024**	**2025**	**2026**	**2027**	**2028**	**2029**	**2030**	**2031**	**2032**	**2033**
Coal Bituminous	189.09	191.29	192.40	191.63	193.26	192.39	188.01	179.93	174.85	168.81	159.36
Natural Gas	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.40	2.36	3.68	4.24
Hydro	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70
Nuclear	14.68	14.09	12.21	14.67	14.58	15.01	13.77	13.77	13.77	13.77	13.77
Diesel	0.48	0.48	0.48	0.48	0.47	0.47	0.47	0.47	0.47	0.47	0.47
Solar	8.22	8.22	8.22	8.22	8.22	10.47	14.11	14.11	17.18	23.80	29.57
Wind	11.10	11.10	11.10	11.10	11.10	11.10	16.45	26.93	37.81	49.09	60.78
Total	224.27	225.88	225.11	226.80	228.34	230.14	233.51	236.33	247.15	260.33	268.90
Fuel type used in Electricity Generation	**2034**	**2035**	**2036**	**2037**	**2038**	**2039**	**2040**	**2041**	**2042**	**2043**	**2044**
Coal Bituminous	150.63	144.48	135.14	118.63	103.26	87.90	72.54	63.55	54.56	45.57	36.58
Natural Gas	5.53	6.53	7.67	9.23	11.08	12.92	14.77	16.52	18.26	20.01	21.76
Hydro	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70
Nuclear	13.77	13.77	13.77	13.77	13.77	13.77	13.77	11.02	8.26	5.51	2.75
Diesel	0.47	0.47	0.47	0.47	0.46	0.45	0.44	0.39	0.35	0.30	0.25
Solar	37.02	37.02	39.60	47.70	54.56	61.41	68.27	77.26	86.26	95.25	104.24
Wind	69.49	82.01	93.71	105.07	118.53	131.98	145.43	152.98	160.53	168.08	175.64
Fuel type used in Electricity Generation	**2045**	**2046**	**2047**	**2048**	**2049**	**2050**					

Coal Bituminous	27.59	24.90	22.20	19.51	16.82	14.12
Natural Gas	23.51	24.21	24.91	25.60	26.30	27.00
Hydro	0.70	0.70	0.70	0.70	0.70	0.70
Nuclear	0.00	0.00	0.00	0.00	0.00	0.00
Diesel	0.21	0.25	0.30	0.35	0.39	0.44
Solar	113.23	117.10	120.97	124.84	128.70	132.57
Wind	183.19	188.64	194.09	199.54	205.00	210.45
Total	348.43	355.80	363.17	370.54	377.91	385.28

7.2.2 Appendix B1: Scenario 3 – Demand Side Management

Table 7-12 summarizes the demand side reduction methods from the energy audits conducted on each building.

Table 7-12: Summary of demand side interventions from the energy audit reports conducted by SEM Solutions

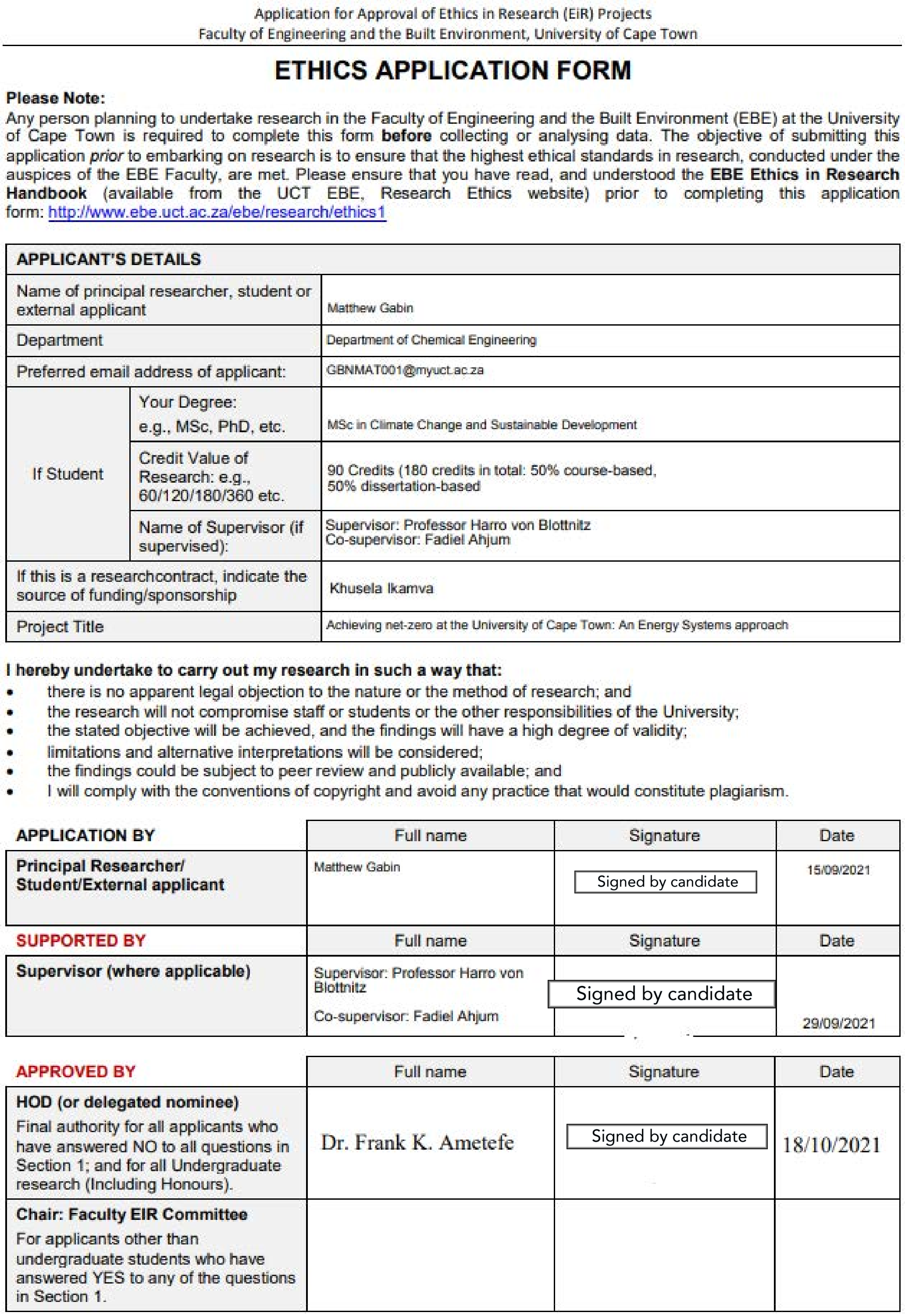
Building	Campus	Short / Mid / Long	Intervention	kWh	Estimated imp. Cost (R)
Anatomy	Health Sc	Long	HVAC - Night purging	1015	64 900
Anatomy	Health Sc	Mid	Lighting - High efficiency lamps and control gear	437731	2 368 800
Bremner	Middle	Long	Lighting - High efficiency lamps and control gear	37768	773 800
Bremner	Middle	Mid	Demand control / load shifting	0	5 500
Falmouth	Health Sc	Long	Lighting - Occupancy control	102993	1 125 300
Falmouth	Health Sc	Long	HVAC - Night purging	3741	64 100
Falmouth	Health Sc	Long	Hot Water - Solar heating	436	90 700
Falmouth	Health Sc	Mid	Lighting - High efficiency lamps and control gear	484889	3 756 500
GH Menzies	Upper	Mid	Lighting - High efficiency lamps and control gear	299531	2 214 400
GH Menzies	Upper	Mid	Lighting - Occupancy control	103758	607 400
GH Menzies	Upper	Mid	HVAC - Night purging	3680	19 800
GH Menzies	Upper	Mid	HVAC - Condenser water temperature reset	9664	56 700
GH Menzies	Upper	Mid	HVAC - CO2 control on fresh air system	24629	216 800
GH Menzies	Upper	Mid	HVAC - Economy cycle	21967	224 500
GH Menzies	Upper	Short	HVAC - Operating hours optimisation	148052	265 700
GSB	GSB	Long	HVAC - CO2 control on fresh air system	18091	224 620
GSB	GSB	Long	Lighting - High efficiency lamps and control gear	18843	490 800
GSB	GSB	Long	Lighting - Occupancy control	6026	128 800
John Day	Upper	Long	Lighting - Occupancy control	22673	309 900

John Day	Upper	Long	HVAC - Night purging	2332	66 700
John Day	Upper	Long	HVAC -Variable primary flow chilled water system	2128	202 300
John Day	Upper	Long	HVAC - Chilled water temperature reset	345	49 800
John Day	Upper	Mid	Lighting - High efficiency lamps and control gear	87804	826 500
John Day	Upper	Mid	HVAC - CO2 control on fresh air system	38003	221 000
Kramer	Middle	Long	HVAC - VSD on cooling tower fans	1620	51 000
Kramer	Middle	Long	Lighting - High efficiency lamps and control gear	215366	2 653 500
Kramer	Middle	Short	HVAC - Condenser water temperature reset	29795	10 200
Kramer	Middle	Short	HVAC - Night purging	46931	26 400
Kramer	Middle	Short	HVAC - Operating hours optimisation	88226	43 000
Kramer	Middle	Short	Demand control / load shifting	0	46 600
Leslie	Upper	Long	Lighting - High efficiency lamps and control gear	549443	5 474 500
Leslie	Upper	Short	HVAC - Condenser water temperature reset	9193	5 100
Leslie	Upper	Short	HVAC - Operating hours optimisation	53198	23 600
MCB	Health Sc	Long	Lighting - Occupancy control	50453	759 900
MCB	Health Sc	Mid	Lighting - High efficiency lamps and control gear	541026	2 459 600
MCB	Health Sc	Mid	HVAC - Heat recovery from chillers	12000	83 692
MCB	Health Sc	Mid	HVAC - Night purging	6684	62 000
MCB	Health Sc	Mid	HVAC -Variable primary flow chilled water system	51642	299 700
MCB	Health Sc	Mid	HVAC - Chilled water temperature reset	8375	49 700
PD Hahn	Upper	Mid	HVAC - Night purging	4230	44 100
PD Hahn	Upper	Mid	Power factor correction	0	230 100
PD Hahn	Upper	Mid	Lighting - High efficiency lamps and control gear	380039	2 939 900
PD Hahn	Upper	Short	HVAC - Condenser water temperature reset	52950	41 500
Robert Leslie	Upper	Long	Lighting - High efficiency lamps and control gear	94737	1 637 600
Robert Leslie	Upper	Long	Lighting - Occupancy control	20618	431 500
Robert Leslie	Upper	Long	HVAC - Night purging	4210	68 200
Robert Leslie	Upper	Long	HVAC - CO2 control on fresh air system	19725	277 600
Robert Leslie	Upper	Long	HVAC - Condenser water temperature reset	1284	58 100
Robert Leslie	Upper	Mid	HVAC - Operating hours optimisation	2041	8 200
RW James	Upper	Long	Lighting - High efficiency lamps and control gear	100094	1 932 100
RW James	Upper	Long	Lighting - Occupancy control	8448	581 900
RW James	Upper	Mid	HVAC - Condenser water temperature reset	1335	10 200
RW James	Upper	Mid	HVAC - Economy Cycle	26766	299 700
RW James	Upper	Mid	HVAC - CO2 control on fresh air system	8379	245 600
RW James	Upper	Short	HVAC - Operating hours optimisation	41227	26 300
RW James	Upper	Short	HVAC - Night purging	3938	13 200

School of Economics	Middle	Long	HVAC - Chilled water temperature reset	3700	48 800
School of Economics	Middle	Long	HVAC - Night purging	2350	63 100
School of Economics	Middle	Mid	HVAC -Variable primary flow chilled water system	21951	111 400
School of Economics	Middle	Mid	Lighting - Day lighting (using existing occupancy sensors)	3931	39 800
School of Economics	Middle	Mid	Lighting - High efficiency lamps and control gear	59083	531 200
Snape	Upper	Long	HVAC -Variable primary flow chilled water system	13149	197 100
Snape	Upper	Long	HVAC - Chilled water temperature reset	2132	49 100
Snape	Upper	Mid	HVAC - Operating hours optimisation	60925	160 000
Snape	Upper	Mid	HVAC - Night purging	8395	63 600
Snape	Upper	Mid	Lighting - High efficiency lamps and control gear	146588	1 186 600
Werner & Beit North	Health Sc	Long	Hot Water - Solar heating	1744	90 300
Werner & Beit North	Health Sc	Long	Lighting - Occupancy control	15518	145 700
Werner & Beit North	Health Sc	Mid	HVAC - Operating hours optimisation	24152	89 400
Werner & Beit North	Health Sc	Mid	HVAC - Night purging	270	6 600
Werner & Beit North	Health Sc	Mid	Lighting - High efficiency lamps and control gear	76624	473 800
Werner & Beit South	Health Sc	Long	Hot Water - Solar heating	872	90 300
Werner & Beit South	Health Sc	Long	Lighting - High efficiency lamps and control gear	68443	763 100
Werner & Beit South	Health Sc	Long	Lighting - Occupancy control	13026	178 400
Werner & Beit South	Health Sc	Mid	HVAC - Chilled water temperature reset	6380	49 300
Werner & Beit South	Health Sc	Mid	HVAC -Variable primary flow chilled water system	37854	294 500

7.3 Appendix C: Ethics Clearance

Below is the ethics clearance form that was approved for this dissertation. It should be noted that the title of this dissertation was adapted to better suit the dissertations aim.



Application for Approval of Ethics in Research (EiR) Projects
Faculty of Engineering and the Built Environment, University of Cape Town

ETHICS APPLICATION FORM

Please Note:
Any person planning to undertake research in the Faculty of Engineering and the Built Environment (EBE) at the University of Cape Town is required to complete this form **before** collecting or analysing data. The objective of submitting this application *prior* to embarking on research is to ensure that the highest ethical standards in research, conducted under the auspices of the EBE Faculty, are met. Please ensure that you have read, and understood the **EBE Ethics in Research Handbook** (available from the UCT EBE, Research Ethics website) prior to completing this application form: http://www.ebe.uct.ac.za/ebe/research/ethics1

APPLICANT'S DETAILS		
Name of principal researcher, student or external applicant		Matthew Gabin
Department		Department of Chemical Engineering
Preferred email address of applicant:		GBNMAT001@myuct.ac.za
If Student	Your Degree: e.g., MSc, PhD, etc.	MSc in Climate Change and Sustainable Development
	Credit Value of Research: e.g., 60/120/180/360 etc.	90 Credits (180 credits in total: 50% course-based, 50% dissertation-based
	Name of Supervisor (if supervised):	Supervisor: Professor Harro von Blottnitz Co-supervisor: Fadiel Ahjum
If this is a researchcontract, indicate the source of funding/sponsorship		Khusela Ikamva
Project Title		Achieving net-zero at the University of Cape Town: An Energy Systems approach

I hereby undertake to carry out my research in such a way that:
- there is no apparent legal objection to the nature or the method of research; and
- the research will not compromise staff or students or the other responsibilities of the University;
- the stated objective will be achieved, and the findings will have a high degree of validity;
- limitations and alternative interpretations will be considered;
- the findings could be subject to peer review and publicly available; and
- I will comply with the conventions of copyright and avoid any practice that would constitute plagiarism.

APPLICATION BY	Full name	Signature	Date
Principal Researcher/ Student/External applicant	Matthew Gabin	Signed by candidate	15/09/2021
SUPPORTED BY	Full name	Signature	Date
Supervisor (where applicable)	Supervisor: Professor Harro von Blottnitz Co-supervisor: Fadiel Ahjum	Signed by candidate	29/09/2021

APPROVED BY	Full name	Signature	Date
HOD (or delegated nominee) Final authority for all applicants who have answered NO to all questions in Section 1; and for all Undergraduate research (Including Honours).	Dr. Frank K. Ametefe	Signed by candidate	18/10/2021
Chair: Faculty EIR Committee For applicants other than undergraduate students who have answered YES to any of the questions in Section 1.			