The Pragmatic Development of a Carbon Management Framework for UK SMEs

By

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Thesis submitted in accordance with the requirements of the University of Liverpool for the degree of Doctor in Philosophy

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Declaration

I hereby certify that this thesis constitutes my own product, that where the language of others is set forth, quotation marks so indicate, and that appropriate credit is given where I have used the language, ideas, expressions or writings of another.

I declare that this thesis is an original report of my own research, has been written by me, and has not been submitted for any previous degree.

Tom S. Johnston
28 February 2023

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Abstract

The UK's commitment to net-zero emissions by 2050 is challenged by critics citing current government strategies as inadequate, marked by a lack of concrete action and aspirational guidelines. Notably, businesses, including small and medium-sized enterprises (SMEs) which constitute about half of all business emissions, are pivotal to this goal. Yet, existing policies and standards often neglect the significant role of SMEs, who face barriers such as limited knowledge and resources in implementing carbon management practices.

This thesis explores the development of a novel carbon management framework specifically designed for medium-sized organisations in the UK to address these problems. The research adopts a practical approach through collaboration with an industry partner, facilitating a case study for real-world application.

Adopting a mixed-methods research design grounded in pragmatism, the study commenced with a qualitative study in the form of a focus group. This exploratory phase, critical for understanding SME challenges, yielded rich data revealing key management themes in strategy, energy, and data. The framework design was supported by a materiality assessment and input from key stakeholders on three major iterations. The final framework comprises three phases: establishing a baseline carbon footprint, creating a carbon reduction plan, and strategically implementing this plan. The validation process, conducted at Knowsley Safari, successfully tested the initial two phases but faced constraints in fully assessing the third phase due to time limitations.

While the research achieved its primary aim of developing a novel carbon management framework for SMEs, it encountered limitations, notably in time and the generalisability of findings due to reliance on a single case study. Future research could test the framework across diverse SME settings to establish its broader applicability and effectiveness in aiding the UK's net-zero emission goals.

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CHAPTER 1

1. Introduction

1.1 Statement of the Problem

Anthropogenic climate change, a significant and complex global challenge of our time, has been well-documented (Firor, 1990; Chandy *et al.*, 2019a; Hase *et al.*, 2021; Wang and Downey, 2023). This term refers to enduring alterations in temperature, precipitation, and other weather patterns, which are largely attributed to human activities. These activities include burning fossil fuels, deforestation, and various forms of land use change (IPCC, 2023a). Over the years, this issue has garnered attention from the public sphere, government bodies, and the scientific community (Scott *et al.*, 2023; Wang and Downey, 2023). Consequently, various initiatives and policies have been implemented to mitigate its effects (Stern, 2007; Urry, 2015). However, the effectiveness of these government policies remains a topic of intense debate within academic circles and the media (Berrang-Ford *et al.*, 2019; LSE Government, 2021; Poynting, 2023).

The role of businesses in the UK's greenhouse gas emissions is a crucial topic for understanding and addressing the climate change challenge. According to official statistics, businesses were responsible for emitting 75.3 MtCO2e1 in 2021, which accounted for 18% of the total greenhouse gas emissions in the UK, shown in Figure 1-1 (Department for Business, 2023). However, there is also evidence of increasing awareness and action among businesses to reduce their environmental impact. A survey conducted in June 2021 revealed that 38% of businesses were taking at least one measure to lower their emissions, while another 24% were planning to act in 2022 (Mullis, 2021). Moreover, in 2021 the UK government announced new regulations requiring some large businesses to disclose their

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[1] *MtCO2e stands for "Mega Tonne of Carbon Dioxide Equivalent". It is a unit of measurement used to compare the emissions from various greenhouse gases based upon their global warming potential (GWP). The GWP for each gas is defined as its warming influence relative to that of carbon dioxide.*

environmental impact, investment products and pension schemes (Timmins, 2021; Department for Business and Trade, 2023).

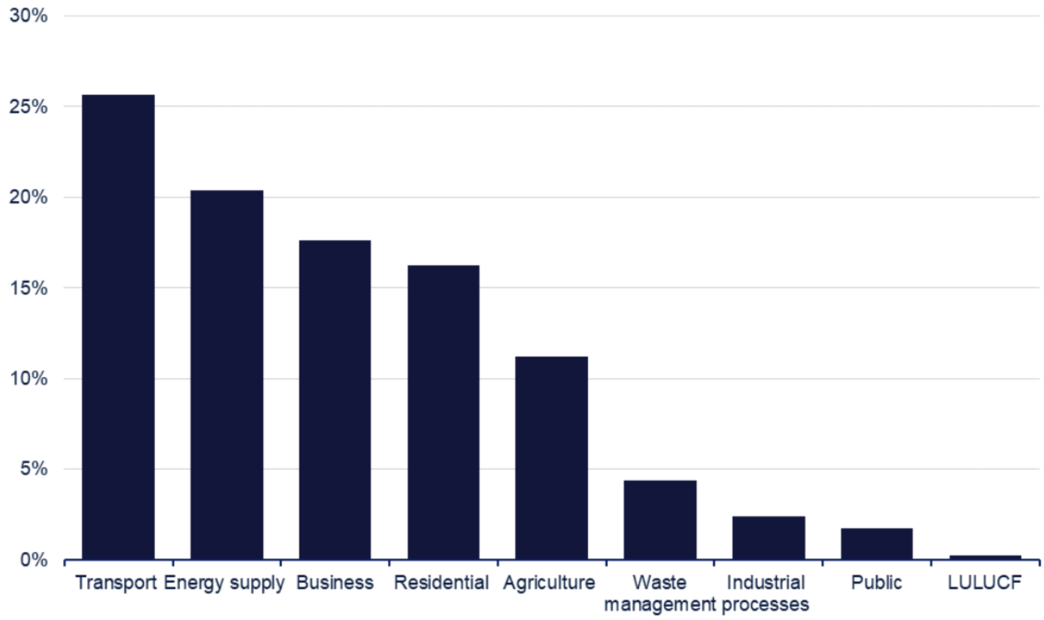


Figure 1-1. Net territorial UK greenhouse gas emissions by NC sector, 2021 (%)
Source: Table 1.2, Final UK greenhouse gas emissions national statistics 1990-2021 Excel data tables.
Note: LULUCF is land use, land use change and forestry.

Businesses find themselves uniquely positioned to contribute to the fight against climate change (Chandy et al., 2019b). As key drivers of innovation and economic growth, they possess the necessary resources and influence to effect significant changes within their operations and supply chains, potentially leading to considerable reductions in emissions whilst boosting company reputation and revenue (KPMG, 2020). Several businesses have already initiated steps to combat climate change (EEA, 2018), whether adopting renewable energy sources, implementing sustainable practices, or investing in innovative technologies.

While we have made some progress, much work still needs to be done (United Nations, 2019; IPCC, 2023a). Climate change is a global concern requiring joint effort from businesses, governments, and individuals. We are already seeing the effects of climate change worldwide, such as rising sea levels and extreme weather events (IPCC, 2023a). The more we postpone addressing this issue, the more profound its impact could potentially become. In the UK, legislation and policies have primarily focused on large businesses over the past two decades. Yet, it is encouraging to see that small to medium-sized enterprises (SMEs) are starting to acknowledge their role in this matter. (Johansson *et al.*, 2019; Gonzales-Gemio, Cruz-Cázares and Parmentier, 2020; Ahmad *et al.*, 2021; Alam *et al.*, 2022).

In 2019, the UK Government became the first major economy to commit to reaching net-zero carbon by 2050 (Priestley et al., 2019). For its time, this ambitious target was established in response to the pressing need to address the global climate crisis and limit the anthropogenic impacts of climate change (Sasse *et al.*, 2020). Achieving net-zero carbon emissions will require significant changes across all sectors of the economy, including energy, transportation, industry, agriculture, and buildings. Table 1-1 highlights the potential impact of small and medium-sized enterprises (SMEs) and their vital contribution to the UK economy, accounting for more than 99.9% of all business and just over 50% of all revenue (UK Gov, 2022a). SMEs play a significant role in job creation, innovation, and economic growth. As the world faces the challenges of climate change, SMEs are increasingly recognised as critical players in driving sustainable development and reducing carbon emissions (Abisuga-Oyekunle et al., 2020; Raghuvanshi and Agrawal, 2020; Smith et al., 2022). While large corporations have historically been the primary focus of efforts to reduce greenhouse gas emissions, SMEs account for a substantial portion of the UK economy (see Table 1-1), and their actions have significant environmental implications.

Table 1-1. 2022 UK Business Population

Business Size	No. of Organisations	Proportion of UK Businesses	Turnover (millions)
All businesses	5,508,935	100%	£4,156,773
SMEs (0-249 employees)	5,501,260	99.9%	£2,124,439
No employees	4,061,035	73.7%	£277,599
1-9 employees	1,187,045	21.5%	£530,456
10-49 employees	217,240	3.9%	£608,852
50-249 employees	35,940	0.7%	£707,532
250 or more employees	7,675	0.1%	£2,032,334

This thesis comprehensively reviews methodologies to reduce carbon emissions in small and medium-sized enterprises (SMEs), focusing on the UK business sector.

It also explores the practices of carbon management and their practical applications within this sector. The literature review's findings primarily drove the research's motivations, investigating the most effective strategies for implementing carbon management within UK-based SMEs.

By adopting a comprehensive view of carbon emissions within the business sector, this research primarily explores operational and embodied carbon emissions while recognising the impacts of activities within the value chain. Finally, the thesis presents a novel methodology for carbon management in SMEs. This approach addresses the fundamental challenges, offering a potential pathway towards more sustainable business practices.

1.2 Aim & Objectives

The primary aim of this thesis is to introduce a novel methodology for implementing carbon management practices within medium-sized organisations based in the UK. To facilitate the achievement of this aim, the following objectives have been outlined:

Objective 1. *To comprehensively review current literature and identify knowledge gaps.*

Objective 2. *Utilise qualitative methods to obtain in-depth insights from industry experts about the challenges and drivers for SMEs in carbon management.*

Objective 3. *Ensure the research methodology is pragmatic, particularly through collaboration with industry partners.*

Objective 4. *Develop a systematic process for SMEs to implement carbon management practices.*

Objective 5. *Apply the findings and outputs of the research to a practical, real-world case study.*

1.3 Research Design & Methodology

Figure 1-2 presents the research design framework and methodology used to deliver the objectives set out in section 1.2

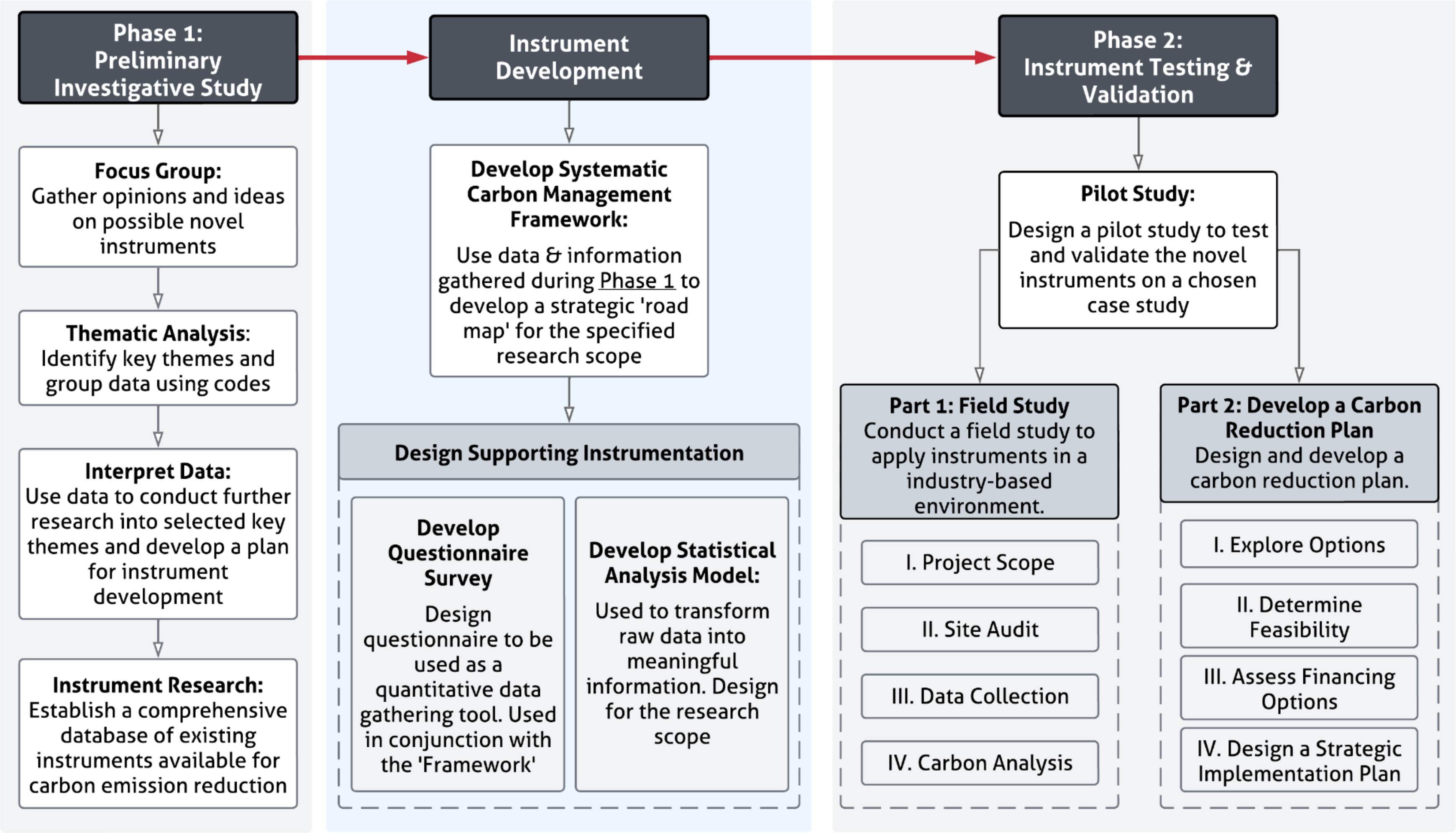


Figure 1-2. Research Design Framework

1.4 Thesis Structure

The structure of this thesis is based on the theory of inquiry, introduced by John Dewey, taking a pragmatic approach to instrument development. A mixed methods approach has been taken, following the **exploratory sequential design: instrument development model**, involving a two-phase approach that uses a qualitative approach to help develop a novel framework and a quantitative methodology for testing and validation.

This thesis, structured on John Dewey's theory of inquiry, adopts a pragmatic approach to instrument development. It employs a mixed-methods approach, using qualitative methods to construct instruments and quantitative methods for testing and validation.

Chapter 2 reviews carbon management practices in the business sector, starting with global climate policy history, narrowing down to UK emissions reporting and national legislative action, and concluding with a systematic literature review of small and medium-sized businesses (SMEs) and corporate carbon management practices. The literature review results in the following research questions:

RQ 1. *How do SMEs perceive carbon management practices within their business, and what is the extent of individual employees' knowledge in this field?*

RQ 2. *Can a generalised framework support UK-based SMEs in reducing their operational carbon impact, adapting techniques currently found at global, national, and corporate levels?*

RQ 3. *Can a UK-based SME achieve net-zero operational emissions at net-zero cost?*

RQ 4. *Would the practice of carbon management in SMEs provide a great enough impact on national emissions to necessitate action from the UK Government?*

Chapter 3 analyses the research methodology and methods used. The philosophical approach and research design are discussed in detail, discussing the research questions derived from *Chapter 2 – Literature Review.*

Chapter 4 initiates the instrument development journey with a focus group study to gather industry insights on carbon management practices and energy efficiency.

Chapter 5 develops a systematic carbon management framework based on the qualitative findings. It outlines three phases: establishing a baseline, developing a carbon reduction plan, and implementing the strategy.

Chapter 6 tests and validates the proposed framework through a case study with Knowsley Safari. The study comprises a field study and a research and development study to test and validate the framework design.

The final chapter summarises the findings, discusses research design limitations, and suggests future work.

1.5 Contributions to Knowledge

Carbon management within the business sector has grown exponentially over the last decade, with new legislation and mandatory carbon reporting requirements released yearly. Despite this new legislation, the methodologies for carbon accounting and reporting, a practice of carbon management, have struggled to keep up and are slowly becoming outdated. Furthermore, a significant lack of methodologies and frameworks specifically focussing on SMEs exists, increasing the gap between large companies and SMEs.

This thesis is composed of original research exploring a novel approach to carbon management within UK-based SMEs. It expands upon previous work, where literature has identified the challenges typically faced when attempting to engage SMEs within the practices of carbon management (Moss, Lambert and Rennie, 2008a; Hendrichs and Busch, 2012a; Conway, 2015a; Hoogendoorn, Guerra and van der Zwan, 2015a; Baranova, 2017), and focusses on taking a pragmatic approach, presenting a practical solution to a growing problem.

A novel and systematic carbon management framework outlines the steps for smaller organisations to account for and report operational carbon emissions. It provides a guide to exploring options for climate mitigation through developing a carbon reduction plan. A testing and validation study demonstrates the proposed framework's functionality and presents the reader with a robust and practical application of carbon management within a UK-based SME.

CHAPTER 2

2. Literature Review

2.1 Study Context

This literature review aims to understand the existing methodologies for reducing and mitigating global carbon emissions across all scales. It explores how these strategies can be implemented within the business sector, encouraging companies to adopt Energy Conservation Measures (ECMs) and reduce operational carbon emissions from business activities.

The review takes a comprehensive approach to carbon reduction and mitigation, encompassing climate science, climate policy, strategic management, operational energy use, emissions accounting and reporting, and green financing. By understanding the fundamentals of climate science and policy, we can establish critical relationships between strategic planning and carbon emissions reduction, laying the groundwork for understanding the process of developing a carbon emissions reduction strategy.

The focus of this review is to provide information for developing carbon reduction and mitigation strategies applicable to small businesses, which constitute a significant portion of the UK economy. The scientific literature, methodologies, and policies published provide the theoretical framework driving climate change adaptation at all levels - be it corporate or state strategy, national or global. The literature elucidates how UK small and medium-sized enterprises (SMEs) can adapt to a rapidly evolving, low-carbon, energy-efficient world.

2.1.1 The Greenhouse Effect and Climate Change

The greenhouse effect is an essential natural process that warms the Earth. It occurs when the Sun's rays reach the Earth's atmosphere; some are absorbed by the surface and re-radiate as heat, which greenhouse gases capture, effectively forming a thermal barrier. This phenomenon keeps the Earth at a temperature capable of sustaining life (Schneider, 1989). Nonetheless, human activities, particularly since the second industrial revolution in the 20th century, have exacerbated the natural greenhouse effect, leading to what is now recognised as anthropogenic climate change (Mitchell, 1989). This intensification is characterised by a significant escalation in natural disasters, extreme weather events, elevated sea levels, and adverse effects on ecosystems, health, and economic structures (IPCC, 1998; Hitz and Smith, 2004; Harley *et al.*, 2006; Bellard *et al.*, 2012; Tol, 2018). The Earth's atmosphere contains various greenhouse gases, including water vapour, carbon dioxide, methane, nitrous oxide, and fluorinated gases (Mitchell, 1989). Among them, water vapour is the most abundant, critically contributing to the regulation of the planet's temperature (IPCC, 2007). While water vapour concentrations result primarily from natural processes, human endeavours can indirectly affect them. The increase in anthropogenic greenhouse gases, such as carbon dioxide, raises global temperatures, enhancing the atmosphere's capacity to retain water vapour. Although this increase in water vapour is a natural response, its amplification due to human-induced emissions significantly contributes to climate change (IPCC, 2007). However, because water vapour persists in the atmosphere for only a brief period (days compared to years), international climate policies prioritise the reduction of long-lived greenhouse gases like carbon dioxide, addressing the root cause of temperature rise and, by extension, secondary effects on water vapour concentrations.

Part 1: The impact of climate policy on the development of carbon management practices

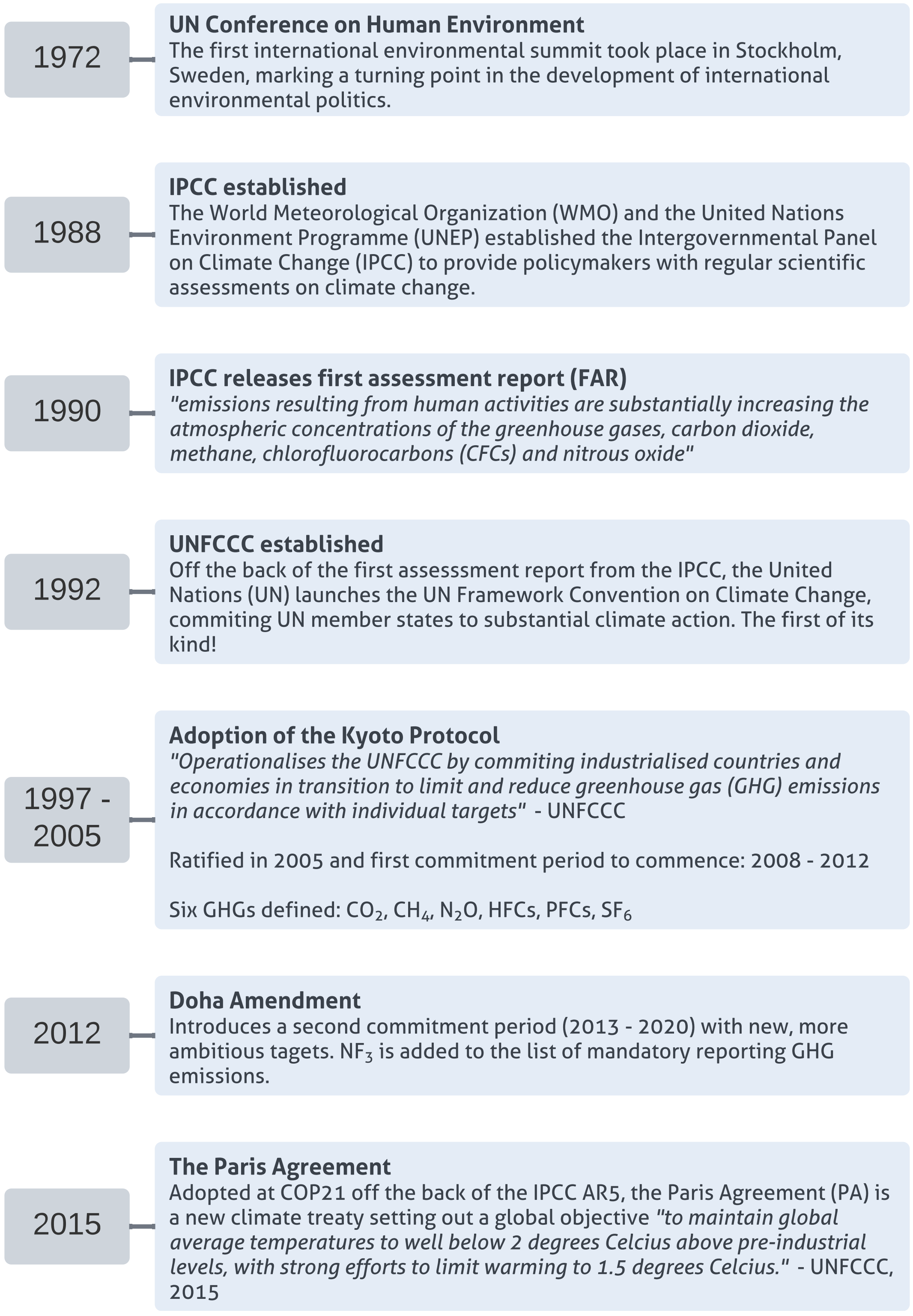
This section presents a selective narrative review of the literature to provide background to the research conducted. While this review is not exhaustive of all available literature nor offers a comprehensive assessment of the field and related academic publications, it strives to present an overarching perspective on the principles, practices, and components of carbon management in the UK at both the national and corporate levels. The review begins by examining how climate policy has evolved over the past four decades, setting the stage for the research presented in this thesis.

2.2 A Brief History of International Climate Policy

Policies, whether from a government or an organisation, have the potential to drive change. The outcomes of policy implementation can often change with varying degrees of success; some are widely adopted, whilst others are opposed and resented. In essence, policies can provide a set of principles that can help address existing problems with real-world, pragmatic solutions.

Climate policy is influenced by years of scientific research and is supported by international organisations like the United Nations and various national governments (WMO and UNEP, no date). The creation of climate policy involves discussions and negotiations between scientists and policymakers, although history has shown this doesn’t always go to plan (Rose, 2014; Meah, 2019). When these two groups work together effectively, it can potentially speed up progress in climate adaptation and mitigation, stimulate the development of low-carbon innovation, and advance strategic planning and methodologies (Lacey *et al.*, 2017; Trancik and Ziegler, 2023).

This section attempts to give a brief overview of climate policy development, as shown in Figure 2-1. It outlines its journey from its early stages to the present day (see sections 2.2.1 to 2.2.4), where the adoption of “Carbon Management Practices” (CMPs) (see section 2.4 for context) are now commonly used worldwide.



1972

UN Conference on Human Environment
The first international environmental summit took place in Stockholm, Sweden, marking a turning point in the development of international environmental politics.

1988

IPCC established
The World Meteorological Organization (WMO) and the United Nations Environment Programme (UNEP) established the Intergovernmental Panel on Climate Change (IPCC) to provide policymakers with regular scientific assessments on climate change.

1990

IPCC releases first assessment report (FAR)
"emissions resulting from human activities are substantially increasing the atmospheric concentrations of the greenhouse gases, carbon dioxide, methane, chlorofluorocarbons (CFCs) and nitrous oxide"

1992

UNFCCC established
Off the back of the first assesssment report from the IPCC, the United Nations (UN) launches the UN Framework Convention on Climate Change, commiting UN member states to substantial climate action. The first of its kind!

1997 - 2005

Adoption of the Kyoto Protocol
"Operationalises the UNFCCC by commiting industrialised countries and economies in transition to limit and reduce greenhouse gas (GHG) emissions in accordance with individual targets" - UNFCCC

Ratified in 2005 and first commitment period to commence: 2008 - 2012

Six GHGs defined: CO_2, CH_4, N_2O, HFCs, PFCs, SF_6

2012

Doha Amendment
Introduces a second commitment period (2013 - 2020) with new, more ambitious tagets. NF_3 is added to the list of mandatory reporting GHG emissions.

2015

The Paris Agreement
Adopted at COP21 off the back of the IPCC AR5, the Paris Agreement (PA) is a new climate treaty setting out a global objective *"to maintain global average temperatures to well below 2 degrees Celcius above pre-industrial levels, with strong efforts to limit warming to 1.5 degrees Celcius."* - UNFCCC, 2015

Figure 2-1. The history of international climate policy - a summarised timeline

2.2.1 IPCC Establishment

The World Meteorological Organisation (WMO) and the UN Environment Programme (UNEP) founded the Intergovernmental Panel on Climate Change (IPCC) in 1988. This collaborative effort sought to inform policymakers through regular scientific assessments detailing climate change impacts, potential risks, and possible response strategies (WMO and UNEP, 2013). This formation marked a critical step in acknowledging and addressing human-induced climate change, which has been recognised since the early 19th century. By 1990, the IPCC published its First Assessment Report (FAR), emphasising the urgency of addressing human-induced greenhouse gas emissions (IPCC, 1992). This landmark report catalysed the 1992 establishment of the United Nations Framework Convention on Climate Change (UNFCCC) (Kuyper, Schroeder and Linnér, 2018) during the Earth Summit in Rio De Janeiro, committing member nations to substantial climate action (Panjabi, 1997).

2.2.2 Kyoto Protocol and Its Evolutions

The release of the IPCC's Second Assessment Report (SAR) in 1995 underpinned subsequent global negotiations, leading to the 1997 Kyoto Protocol adoption at COP 3 (Foster, 2001). Despite its delayed enforcement in 2005, the Kyoto Protocol marked an unprecedented commitment from developed nations to curtail greenhouse gas (GHG) emissions (predominantly CO_2) (United Nations, 2020). The protocol introduced robust emissions reporting and compliance mechanisms, although global emissions continued to surge.

Recognising the need for more stringent action, the international community instituted the Doha Amendment, initiating a second commitment period (2013-2020) and expanding GHG targets and types (ERBACH, 2015). However, the increased ambition faced setbacks, with key nations like Canada and the United States disengaging, undermining global consensus and urgency (United Nations, 2020b).

2.2.3 Transition to the Paris Agreement

The 2015 Paris Agreement, adopted at COP 21, emerged as a flexible yet ambitious global response to climate change, fortified by the scientific findings of the IPCC's Fifth Assessment Report (AR5) (Jayaraman, 2015). It operates on a legal framework and includes various legally binding provisions; however, the nature of its obligations is a mix of mandatory and voluntary elements (UNFCCC, 2015). Unlike its predecessors, the agreement encouraged nations' individualised commitments, enhancing participation and ownership over climate strategies (Falkner, 2016). The inclusive negotiation approach facilitated by the French

Presidency, characterised by transparency and accommodation, played a crucial role in reaching this consensus (Dimitrov, 2016).

Though celebrated for its universal acceptance and flexible framework, the Paris Agreement now faces the reality of implementation (Savaresi, 2016). Its success hinges on global stakeholders harnessing technological innovation, financing, and transformative policies to actualise the commitments (Hulme, 2016; Ollila, 2019). As climate actions unfold, they must be rooted in the evolving scientific understanding and societal recognition of the existential threat of climate change (Hulme, 2016).

2.2.4 Climate Policy Since the Paris Agreement – A 2023 Update

Since the adoption of the Paris Agreement in 2015, there have been few significant updates in international climate policy. The period following the agreement has been marked by a mix of progress, ongoing efforts, and significant hurdles (Ollila, 2019; Jakučionytė-Skodienė and Liobikienė, 2022; Meinshausen *et al.*, 2022; Schleypen *et al.*, 2022; Victor, Lumkowsky and Dannenberg, 2022). It has been observed that the urgency of the problem (anthropogenic climate change) has been amplified by substantial evidence of climate-related disasters (Formetta and Feyen, 2019; Chen *et al.*, 2020; Ripple *et al.*, 2022) and scientific warnings (IPCC, 2023b). While there have been advancements, especially in national policies (see section 2.3) toward the transition to renewable energy (Østergaard *et al.*, 2020; Presno and Landajo, 2021; Tian *et al.*, 2022; Murshed, 2023) and net-zero targets (Sasse *et al.*, 2020; van Soest, den Elzen and van Vuuren, 2021; Poynting, 2023; Van Coppenolle, Blondeel and Van de Graaf, 2023), critical sticking points remain, particularly around finance, equity, and the operational details of international cooperation (Khalifa *et al.*, 2022; McKinsey & Company, 2022; Lee, Hengesbaugh and Amanuma, 2023).

2.3 An Outlook on National Emissions in the UK

The primary focus of this review is an in-depth examination of the evolution of climate policy within the United Kingdom (UK) and its consequential impact on reducing national carbon emissions, achieved significantly through the implementation of strategic government policies, initiatives, and programs. This study not only highlights the successful outcomes but also delves into the challenges encountered and criticisms levelled against specific governmental resolutions, situating the UK as a pivotal figure in global climate governance (Poortinga *et al.*, 2011; Lockwood, 2013; Gillard, 2016; Willis, 2019; WNN, 2019).

2.3.1 Global Analysis of the UK's Climate Action

The United Kingdom's commitment to climate mitigation and adaptation has drawn international acknowledgement, particularly highlighted when the nation became the fourth-leading country in global climate action, according to the 2020 Climate Change Performance Index (CCPI) (Burck et al., 2020). This highlights the UK's ongoing efforts in addressing the multifaceted challenges of climate change mitigation.

Nonetheless, by 2023, the UK has experienced a steady decline, falling to eleventh in the CCPI rankings. While still classified among the "high performers," this downward shift emphasises specific shortcomings in the nation's climate strategy (CCPI, 2023b). This decline in ranking is mainly attributed to the absence of decisive policies aimed at phasing out oil and gas extraction, a critical factor in limiting global warming (McGlade and Ekins, 2015), and a perceived lack of tangible measures to achieve its ambitious 2050 net-zero emissions target (Renukappa *et al.*, 2021; Walk and Stognief, 2022).

The CCPI employs a comprehensive evaluation methodology encompassing four pivotal fields: greenhouse gas (GHG) emissions, the integration of renewable energy sources, the patterns of energy demand, and the overarching strategies within climate policy (Puertas and Marti, 2021; CCPI, 2023a). This rigorous analytical framework allows for an all-encompassing assessment of participating countries' performances in their climate pursuits (Burck *et al.*, 2020)

The UK's recent backslide in the rankings highlights the essential, albeit challenging, balance that countries must maintain between immediate action and sustainable long-term strategies. It emphasises the need for constant reassessment and recalibration of policies to ensure alignment with global climate goals and the evolving scientific understanding of climate change impacts. Furthermore, it serves as a reminder that earlier successes do not allow a company to take a step back; instead, they should encourage further commitment and more tangible actions in the battle against global climate change. This historical context sets the stage for critical reflections on policy effectiveness and areas necessitating more robust attention and resources.

2.3.2 An Overview of National Emissions Reporting

Analysing economic trends, the UK government employs a sector-based strategy for crucial policy decisions within its industrial framework. The Department for Business, Energy, and Industrial Strategy (BEIS) adopts this methodology in its annual greenhouse gas (GHG) emissions report, offering nuanced insights into emissions by sector, fuel, and GHG type. This systematic categorisation informs two primary publications:

1. **Final Figures Report** (released in Q1) detailing definitive GHG emissions data from two years prior.
2. **Provisional Figures Report** (released in Q2) offering preliminary emissions estimates from the preceding year.

Each report juxtaposes current findings with historical data, facilitating a comprehensive review of emission trends. They initially summarise year-on-year changes, followed by an introduction clarifying the report's objectives and methodology. Notably, emissions are assorted into nine high-level sectors per the Intergovernmental Panel on Climate Change (IPCC) guidelines to preclude data discrepancies (IPCC, 1996, 2019; BEIS, 2020). These sectors include:

1. Energy supply
2. Business
3. Transport
4. Public
5. Residential
6. Agriculture
7. Industrial processes
8. Land use, land use change and forestry (LULUCF)

9. Waste management

This detailed sectoral analysis plays a supportive role, offering insights for stakeholders like businesses, analysts, and researchers by identifying emission intensity areas and suggesting possible mitigation paths. It also highlights the utility of organised national emissions databases. These comprehensive records contribute to advancing scientific research in climate mitigation and encourage technological progress by indicating critical focal points for investment and policy formulation (Zafar *et al.*, 2019; Erdoğan *et al.*, 2020; Erdogan, 2021; Godil *et al.*, 2021; Stern and Valero, 2021).

The researcher believes that, while the UK's sector-based reporting system is commendable for its thoroughness, it is imperative to question its real-world impact: Does detailed reporting translate to effective policy formulation? Furthermore, reliance on data from previous years, especially in the 'Final Figures Report,' may lead to policy decisions that, while data-driven, are retrospectively responsive rather than pre-emptively strategic.

Additionally, while the IPCC framework ensures consistency and comparability across nations, the potential exists for the UK's industrial and energy sectors to be overshadowed by the rigidity of predefined categories. The researcher thinks the system must maintain flexibility to adapt to the UK's evolving economic landscape.

The government's role should not be limited to disclosure but must extend to fostering environments conducive to innovation and investment in emissions reduction (Grubb, 2004; Gans, 2012; Fried *et al.*, 2018). To conclude, while the annual government reports potentially guide strategy, their effectiveness would be considerably enhanced by policies incentivising rapid, targeted action and investment in the sectors identified as critical emission contributors.

2.3.3 The UK's Commitment to Climate Change

The UK, post-Kyoto Protocol, embarked on an ambitious legislative journey, crafting comprehensive climate policies that often-exceeded international mandates; some of these are highlighted in Table 2-1[1]. However, an academic

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[1] Table 2-1 *illustrates the chronological progression of relevant legislation and targets from 2006 to 2019, highlighting national, EU, and international efforts.*

perspective questions the environmental efficacy of these ambitious legislative frameworks and targets (Kyllönen, 2017). The effectiveness of these policies is contingent upon their practical implementation, ongoing monitoring, and the concrete outcomes they produce beyond theoretical plans (Ryan, 2015; Bostrom, Hayes and Crosman, 2019).

Table 2-1. Key National, EU, and International Legislation Influencing UK's Emission Reduction Targets

Period	Target or Legislation	Description	Source
2006	National Legislation: Climate Change and Sustainable Energy Act	Set out to boost the number of UK heat and electricity microgeneration installations—amendments to the Gas Act 1986 and Electricity Act 1989.	(UK Government, 2006)
2008 – 2012 (inclusive)	National Target: Kyoto Protocol – First Commitment Period	To reduce total GHG emissions by 12.5% below baseline (1990) levels over a 5-year period (2008-12) under the EU burden sharing agreement.	(DECC, 2015) (Ainslie and Clarke, 2019)
2008 - 2019	National Legislation: The Climate Change Act 2008	An 80% reduction in GHG emissions by 2050 compared with the 1990 baseline.	(UK Government, 2008b)
2009	EU Legislation: 2020 Climate & Energy Package	A binding legislation to ensure the EU and its member states meet climate targets set for 2020: - A reduction of 20% in GHG emissions (from 1990 levels) - 20 % of EU energy from renewables - 20% improvement in energy efficiency	(European Commission, 2009)
2013 – 2020 (inclusive)	National Target: Kyoto Protocol – Second Commitment Period	GHG emission reduction target of 20% by 2020 compared with 1990 levels (base year)	(DECC, 2015)
2016	National Target: The Paris Agreement NDC	Nationally Determined Contribution (NDC) of -40% in GHG emissions by 2030 compared with 1990 levels	(EU, 2015; CCC, 2016)

2019	National Legislation: The Climate Change Act 2008 (2050 Target Amendment) Order 2019	At least a 100% reduction in GHG emissions by 2050 compared with the 1990 baseline. To achieve net zero carbon emissions by 2050.	(Sara Priestley, 2019)
2021	National Target The Sixth Carbon Budget	To reduce emissions in 2030 by at least 68% compared to 1990 levels. Cutting emissions by 78% by 2035 compared to 1990 levels.	(BEIS, 2021b)

2.3.3.1 The Pragmatic Approach: Beyond Aspirational Guidelines

This research highlights the necessity for pragmatism in executing these climate policies. Achieving the 2050 net-zero target, referenced in Table 2-1, remains uncertain, with literature highlighting some of the distinct challenges the UK is likely to face in the upcoming years (Castle and Hendry, 2023). Others challenge the likeliness of achieving the 2050 goal, suggesting a revision for the UK’s legislated targets that are strengthened and backed by clear political direction (Pye *et al.*, 2017). The researcher advocates for a strategy prioritising tangible action and verifiable progress over aspirational guidelines, thereby more assuredly steering the nation towards its emissions reduction objectives. This approach focuses on real-world applicability, adaptability to changing circumstances, and a commitment to achieving measurable climate change adaptation and mitigation results.

2.3.3.2 Influence of EU Policy and the Post-Brexit Challenges

The UK's climate commitments were initially steeped in broader EU directives, influencing the nation's approach and integration within a more extensive network of climate-responsive economies (Burns, 2023). However, the effectiveness of such policies is only partially dependent on their ambitious nature but also their execution, the verifiable environmental impact, and the social and economic repercussions (Nash and Steurer, 2019; Skjærseth, 2021).

While the UK government set commendable targets following the Kyoto Protocol, it is essential to scrutinise the actual progress made towards these goals. Statutory milestones are the first step; the real challenge lies in consistent policy enforcement, proactive strategies encompassing industrial compliance, and public engagement in climate action. There is a palpable need for data and discourse around the real-term emission reductions achieved, exploring the gap, if any, between legislative intent and climate change mitigation.

The UK's journey should not be assessed in isolation; a comparative analysis with similar economies is essential to gauge the nation's global standing in climate responsiveness (Biesbroek *et al.*, 2010; Ylä-Anttila *et al.*, 2018). Are we leading, following, or lagging? This introspection is crucial considering the dynamic international landscape, especially in the post-Brexit era. The UK's departure from the EU necessitates analysing how this geopolitical shift has influenced its climate policies (Farstad, Carter and Burns, 2018; Moulton and Silverwood, 2018; Burns, 2023). Are we maintaining the rigour afforded by collective European targets, or has this departure led to legislative leniency?

2.3.3.3 Economic Perspectives: Insights from the Stern Review and Beyond

In 2006, the Stern Review underscored the economic ramifications of climate change, advocating for immediate, robust action to preclude more severe global consequences (Stern, 2007). This landmark analysis catalysed the introduction of the Climate Change Act 2008, a legislative cornerstone that positioned the UK as a leader in global climate strategy, setting out ambitious objectives (UK Government, 2008a). The Stern Review highlighted the economic argument for climate action (Nordhaus, 2007; Weitzman, 2007). However, the broader implications of this economic shift, including regional disparities, industrial impacts, community responses, and job creation within the emergent green economy, require attention (Antal and Van Den Bergh, 2016; Stern, Stiglitz and Taylor, 2022). The transition is not without its socio-economic costs, and a balanced discourse must address the beneficiaries and the casualties of this legislative evolution (Lefèvre *et al.*, 2022).

2.3.3.4 Contemporary Challenges: COVID-19 Pandemic and Urgency of Adaptation

After the Climate Change Act of 2008 was established(UK Government, 2008b), it might be beneficial to consider not only focusing on setting goals but also exploring the ongoing challenges within current climate policy. For instance, the COVID-19 pandemic has impacted global economies and, by extension, climate action.

(Hepburn *et al.*, 2020; Klenert *et al.*, 2020; Zang *et al.*, 2021). Has the UK recalibrated its climate strategy considering such unprecedented global crises? Moreover, with the growing urgency around climate threats, are we adapting our policies to mitigate emerging risks? To answer these questions is complex and multifaceted. The researcher believes that the effectiveness of policies in mitigating the risks of climate change varies widely based on the specific policies implemented, the extent of their implementation, the area or sector they cover, and how they are perceived and acted upon by businesses, governments, and individuals.

2.3.3.5 Legal Commitments and the Road Ahead: Setting and Pursuing Ambitious Targets

As the UK legally committed to a net-zero emissions target by 2050 (see Table 2-1), the stage is set for a climate change-focused overhaul of various economic sectors as presented in the numerous strategies set out by the UK government (Walker and Carver, 2023). However, this legal commitment's validity will be tested by its implementation plan (DESNZ and BEIS, 2023), the adaptability of the strategies encompassing unforeseen future challenges, and the country's ability to maintain its climate leadership on the global stage, as addressed in the latest progress report by the Committee on Climate Change (CCC, 2023). Critically, the voices advocating for an earlier target emphasise the need for legislative ambition and urgency in action (Gudde *et al.*, 2021; Client Earth, 2023; Harvey, 2023a; Masoud Sajjadian, 2023).

The researcher believes that while the UK's legislative framework for climate action is comprehensive and ambitious, it necessitates critical review and constant evolution. The real-world impacts, the broader economic and social implications, and adaptability to local and global challenges are crucial indicators for success. If the UK is genuinely going to achieve net-zero emissions by 2050, it must address the challenges head-on. Taking a pragmatic approach to climate change mitigation and introducing tangible actions across all areas of the economy, including a more granular approach to business emissions. In the researcher's opinion, sector-specific frameworks and guidance methodologies are required to address the multifaceted challenges faced by diverse organisations operating in the UK.

2.3.4 A Critical Review of the UK’s Climate Action (as of 2023)

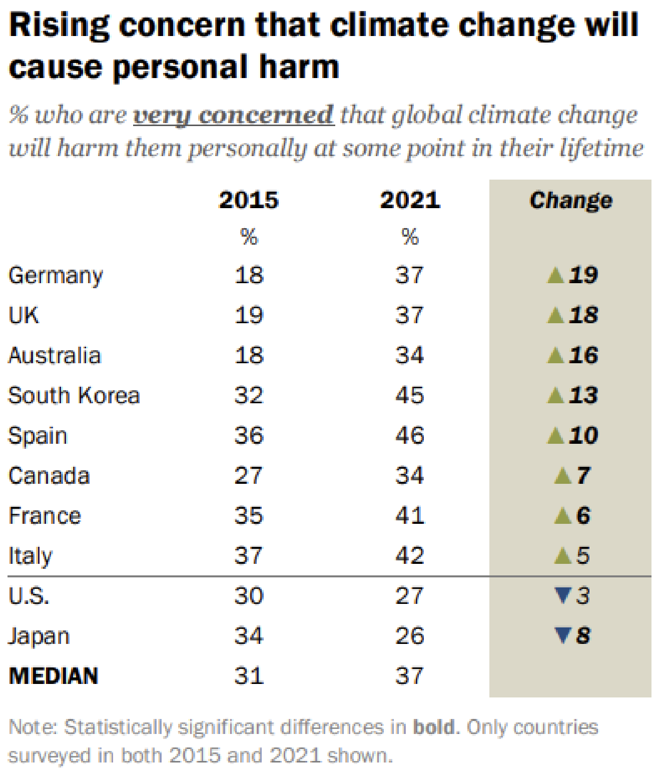
The global community has been intensifying its efforts to combat the undeniable and escalating threats of climate change. In this context, the United Kingdom has emerged as a significant player. Rooted in historical industrialisation and modern advancements, the UK's climate policies reflect a blend of ambition, urgency, and adaptation, especially in the aftermath of international agreements like the Paris Agreement (discussed in section 2.2.3). This section aims to provide an in-depth analysis of the UK's strides and stumbling blocks in its journey toward net-zero. From public perceptions and evolving policy documents to the challenges posed by real-world implementation and the overlooked sectors in this vast landscape, an exploration into how the nation navigates its climate commitments and where it stands in 2023 is discussed.

2.3.4.1 Global Context and Imperative

Faced with the escalating threats of climate change, the United Kingdom stands at the forefront of a global imperative in the aftermath of the Paris Agreement. With a drive to meet the legally binding target of achieving net-zero emissions by 2050 (detailed in Table 2-1, Section 2.3.3.), the UK commits to adjusting its climate policies and developing strategies. This urgency does not just resonate within the confines of policymaking but is a response to emphatic scientific warnings, as outlined by the latest IPCC reports, signalling a tipping point that demands unparalleled global action (IPCC, 2014, 2023b).

2.3.4.2 Public Perception and Willingness

In 2021, researchers at the Pew Research Center conducted a survey in 17 developed nations in North America, Europe, and the Asia-Pacific on the attitudes toward climate action, both globally and within their respective nations. Results highlighted the widespread concern about the personal impact of global climate change, with most respondents willing to change the way they live and work but unsure of whether their efforts will make a substantial impact (Bell *et al.*, 2021). Between 2015 and 2021, there was an 18% increase in UK residents' concerns about the personal effects of climate change, as illustrated in Figure 2-2. The survey indicated a notable optimism among UK inhabitants. Roughly seven in ten expressed confidence in the nation's response to climate change, with an impressive 84% conveying their readiness to make lifestyle adjustments to curtail carbon emissions (Bell *et al.*, 2021).



Rising concern that climate change will cause personal harm

*% who are **very concerned** that global climate change will harm them personally at some point in their lifetime*

	2015	2021	Change
	%	%	
Germany	18	37	▲**19**
UK	19	37	▲**18**
Australia	18	34	▲**16**
South Korea	32	45	▲**13**
Spain	36	46	▲**10**
Canada	27	34	▲**7**
France	35	41	▲**6**
Italy	37	42	▲5
U.S.	30	27	▼3
Japan	34	26	▼**8**
MEDIAN	31	37	

Note: Statistically significant differences in **bold**. Only countries surveyed in both 2015 and 2021 shown.

Figure 2-2. Pew Research Center Survey Results on the Attitudes Toward Climate Change (Bell *et al.*, 2021)

The researcher believes this situation highlights the significance of crafting clear and sensible policies. Individuals are open to contributing their share, hoping their actions have a meaningful impact. As the UK refines its climate strategies, it does so under the attentive eyes of its residents and the international community. The steps the UK is taking, though just a part of a global effort, may offer a sense of encouragement and spark initiative among communities globally.

2.3.4.3 The UK's Net-Zero Strategy

The United Kingdom is actively pursuing a green agenda to curb carbon emissions. From its *ten-point plan for a green industrial revolution* (BEIS and DESNZ, 2020b) to its first net-zero strategy – *Build Back Greener* (BEIS and DESNZ, 2021b), to the latest updates published under the policy paper – *Powering Up Britain: Net Zero Growth Plan* (DESNZ and BEIS, 2023). These policy documents, in addition to more specific strategies (outlined in Table 2-2), highlight the plans put in place.

Table 2-2. UK Government Net Zero Policy Documents

Policy Document	Date Released	Source
Energy White Paper: Powering Our Net Zero Future	December 2020	(BEIS and DESNZ, 2020a)
Industrial Decarbonisation Strategy	March 2021	(BEIS and DESNZ, 2021a)
Decarbonising Transport: A Better, Greener Britain	July 2021	(DfT, 2021)
UK Hydrogen Strategy	August 2021	(BEIS and DESNZ, 2021c)
Heat and Buildings Strategy	October 2021	(BEIS, 2021a)
British Energy Security Strategy	April 2022	(BEIS and DESNZ, 2022)
Green Finance Strategy	March 2023	(BEIS, 2023b)

2.3.4.4 Implementation and Criticisms

The policies set out in Table 2-2 have seen the implementation of various carbon reduction schemes, including promoting the adoption of renewable energy, enhancing energy efficiency, and incentivising alternative transportation methods, including plug-in hybrid and fully electric vehicles.

The UK's strategy, chronicled through evolving policy documents (refer to Table 2 2), signals a robust commitment but invites questions about its efficacy and comprehensive impact. While groundbreaking in their scope, these documents have elicited concerns regarding their implementation feasibility, with critics pointing to potential economic strain and the challenges of securing industry-wide compliance (Skidmore, 2022; Harvey, 2023b; Masoud Sajjadian, 2023).

2.3.4.5 The Renewable Energy Dilemma

In the researcher's opinion, the real-world application for climate action has yet to meet the expectations outlined in numerous policy documents. For instance, the expansion of renewable energy sources is commendable but seems lagging when benchmarked against other nations such as Germany and China (Chapman, 2023; Otugour, 2023). While the government promotes the green industrial revolution, opposition highlights the lack of support for workers transitioning from traditional energy sectors, suggesting a disparity in stakeholder impact (Skidmore, 2022; Cavina *et al.*, 2023).

2.3.4.6 Overlooking the Role of SMEs

Despite their significant contribution to the UK's economy and greenhouse gas emissions, SMEs often need to be more supported in significant climate action policies (Conway, 2014, 2015b). The current policies primarily focus on large corporate entities, inadvertently overlooking the critical role of small and medium-sized enterprises (SMEs) in carbon emissions. This gap in policy inclusivity calls into question its comprehensive effectiveness, as Mole and Belt (2023) discuss. This concern is of significant interest when considering 0SMEs' substantial economic footprint, contributing to over 50% of the UK's total revenue (UK Gov, 2022a). Furthermore, the British Business Bank (2021) reported that SMEs are responsible for an estimated 43-53% of greenhouse gas emissions from businesses and about 29-36% of the UK's total emissions, presented in Figure 2-3. While the emissions of individual SMEs might seem minimal on a case-by-case basis, their collective environmental impact is a significant component of the UK's overall emissions and economy (British Business Bank, 2021). Hence, the researcher believes that any approach aiming for comprehensive climate action striving to reach net-zero must address SMEs' challenges and acknowledge their collective influence.

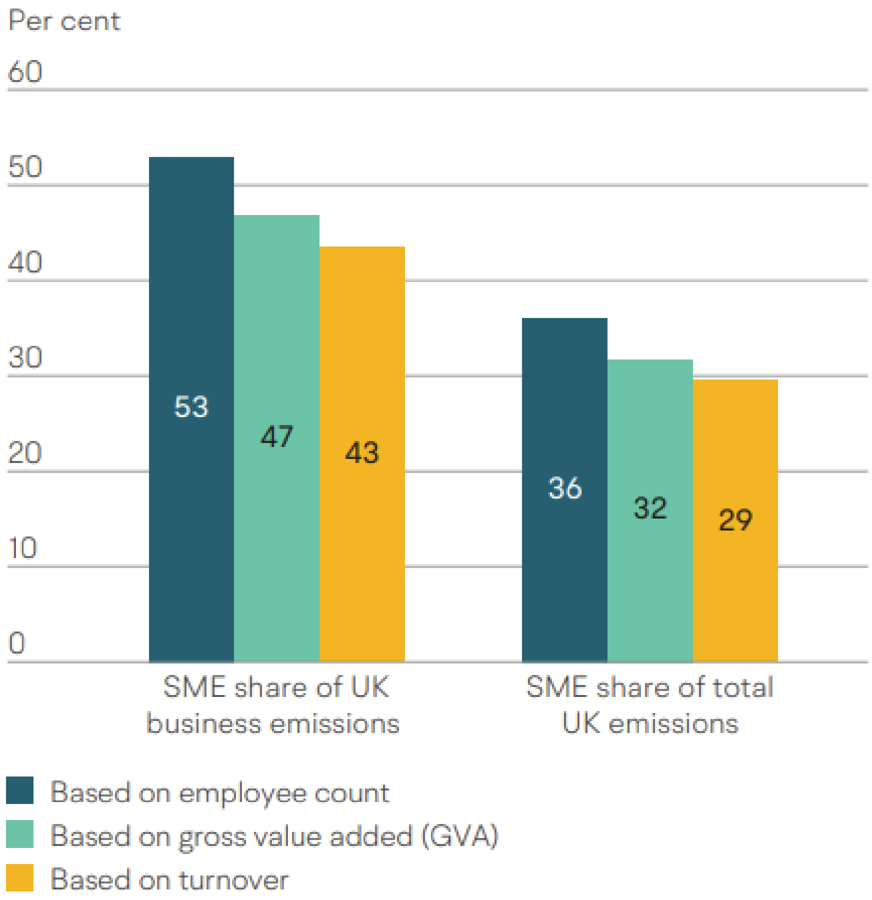


Figure 2-3. Estimate share of UK territorial greenhouse gas emissions from SMEs British Business Bank (2021)

2.3.4.7 Reflections and Implications: The Road Ahead

As of 2023, the UK's climate policies are changing regularly; with a national election in 2024, politicians are using climate action to gain popularity with the British public. While foundational steps have been impactful, experts advocate for more aggressive measures (Skidmore, 2022; Climate Change Committee, 2023), mindful of the evolving technological landscape and the imperative for global collaboration (Cavina *et al.*, 2023; Climate Change Committee, 2023).

The researcher believes the UK's environmental efforts represent a notable advance in global environmental governance. However, this analysis emphasises the potential benefits of regular review, open public discussions, and adaptable policymaking. The aim would be to see climate promises realised in real-world actions. The author believes it might be beneficial to consider a perspective encompassing both large corporations and small businesses, especially given the contribution of SMEs to UK emissions, refer to Figure 2-3.

Moreover, there may be some merit in the UK government giving thought to strategies that directly touch upon the country's carbon reduction obstacles. A prime example is the thermal efficiency of UK housing, particularly in the social housing sector. A report published by the Grantham Institute for Climate Change and the Environment suggests that the energy efficiency of UK homes ranks amongst the lowest in Europe and loses heat up to three times faster (Baker *et al.*, 2022). This deficiency should be addressed before investing in advanced technological solutions such as solar PV or air-source heat pumps. Whilst the UK attempts to address this issue with its latest ECO4 scheme (BEIS, 2022), criticism remains around its effective rollout (Citizens Advice, 2021; Watson *et al.*, 2023).

To add to this issue, the UK government promotes air source heat pumps as replacements for natural gas boilers; without proper retrofitting of the existing housing infrastructure, these systems can be costly to install and may not efficiently heat homes, leading to higher operational costs.

2.3.5 Concluding Remarks on UK Climate Action

As the global discourse on climate change continues to gain momentum, the United Kingdom stands as both a beacon of progress and a subject of critical examination. The nation's endeavours, from comprehensive policy documents to implementation efforts, exemplify its commitment to the global goal of achieving net-zero emissions. However, the journey is far from linear. The challenges faced, such as the proper inclusion of SMEs in climate strategies, the enhancement of housing thermal efficiency, and the real-world application of renewable energies, highlight the nuances and complexities inherent in such a transformative undertaking. Public sentiment, as evidenced by the Pew Research survey, indicates a populace ready and willing to pivot towards sustainable practices. The UK's responsibility now lies in ensuring its policy frameworks are ambitious but also holistic, inclusive, and effective. The nation's climate journey serves as both an inspiration and a lesson for the world, emphasising adaptability, continuous evaluation, and collective action in the face of an evolving environmental landscape.

2.4 Carbon Management: An Overview

Carbon management (CM) is a comprehensive approach that includes various procedures, methodologies, and strategic decisions to manage carbon dioxide equivalent (CO_2e) emissions[2]. These strategies can be applied across diverse scales, from businesses and cities to national and global arenas. At its core, CM is dedicated to overseeing the carbon emissions pertaining to the scope of a particular project. As the Journal of Carbon Management aptly puts it:

"Carbon management is the options and mechanisms for mitigating the causes and impacts of climate change" - (Garg and Gillenwater, 2010)

The domain of CM touches upon several key themes (Houghton and Dhakal, 2010):

- GHG mitigation and adaptation.
- Metrics for carbon reduction.
- International treaty-driven mechanisms, such as those from the Kyoto Protocol and the Paris Agreement (refer to section 2.2 for information on climate policy).
- Domestic carbon policies and environmental impact assessments (EIA).
- Carbon management (CM) technologies and innovations.
- Collaborative industrial initiatives.
- Consumer choices in energy consumption.

Furthermore, it covers the broader areas of carbon footprinting and accounting, land use modifications, agroforestry, and energy monitoring. It scrutinises the entirety of the energy lifecycle, encompassing stages from resource extraction, such as mining and drilling, to the utilisation of energy from various sources—fossil fuels, nuclear energy, and renewables like wind and solar. It even encompasses energy storage solutions, like batteries and hydrogen fuel cells (Runci and Dooley, 2004).

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[2] *CO2e emissions refers to 'carbon dioxide equivalent' emissions and is used to report all GHGs under a common reporting term, essentially grouping the basket of seven GHGs outlined in the Kyoto Protocol (see Figure 2-1 in section 2.2) into a singular figure for simplified carbon accounting and footprinting.*

A unique aspect of carbon management is its multidisciplinary nature. It interfaces with the primary segments of the carbon cycle: the atmosphere, land, oceans, and fossil fuels (Houghton and Dhakal, 2010) and their relative industrial, political, and scholarly fields. Schaltegger and Csutora (2012a), discuss the importance of CM in a corporate organisation as an essential step in reducing carbon emissions, stating that the field of carbon management is being built into the managerial structure of companies to not only comply with regulations and to adapt to societal pressures, but also to instinctively incorporate carbon-related issues into their business models, company ethos, and business values.

2.4.1 Corporate Carbon Management Practices

As with most corporate practices, highly developed strategies and management techniques have evolved, providing well-established methods for others to follow. These practices encompass a range of activities, including the measurement, reporting, and management of greenhouse gas (GHG) emissions stemming from an organisation's operations. The goal is to develop financially viable strategies that mitigate and reduce these emissions (Zhou, 2020b).

Doda *et al.* (2015) explore the relationship between implementing carbon management (CM) practices and their efficacy in reducing GHG emissions. Their study reviewed the CM practices employed by major corporations in 2010, attributing scores to various metrics to quantify changes in emissions intensity. They identified 23 practices and categorised them into four overarching areas: 'Policy and Targets', 'Measurement', 'Management and Decision-Making', and 'Disclosures'. Similarly, Zhou (2020b) defines carbon management into four essential components: 'Measurement of carbon footprint', 'Mitigation measures', 'Cost-effectiveness', and 'Integration into business strategy across the value chain'. Additionally, Galán-Valdivieso *et al.* (2019) examine carbon-related factors that enhance a corporation's legitimacy and influence on stakeholders. The study delineates four groups of corporate carbon policies, similar in nature to CM practices: 'Carbon operations', 'Carbon emissions tracking', 'Carbon governance', and 'Reporting and disclosure'.

Numerous other studies have attempted to outline and assess the performance of CMPs or the carbon strategies used in corporate organisations (Kolk and Pinkse, 2005; Jeswani, Wehrmeyer and Mulugetta, 2008; HEFCE, 2010; Sullivan and Gouldson, 2012; Luo and Tang, 2014; Guenther *et al.*, 2016; Herold and Lee, 2019;

Shrestha, 2021), Table 2-3 attempts to collate the common CMPs discussed in the literature available.

Table 2-3. Typical Corporate Carbon Management Practices

Carbon Management Stage ***Overarching Practices***	**Carbon Management Practices** ***Specific Metrics***
Company Policy	Defining Business Drivers
	Business Strategy
	Science-based Target Setting
	Materiality Assessment & Stakeholder Involvement
Measurement	Carbon Accounting & Footprinting
	Data Collection & Analysis
	Life-cycle Assessment (LCA)
	Operational & Embodied Carbon Assessment
	Building Energy Modelling (BEM)
	Climate change scenario analysis
Management	Inventory Management
	Carbon Mitigation Measures
	Energy/Carbon Forecasting & Modelling
	Implementation Strategies
	Financial Incentives & Cost-effectiveness
	Marginal Abatement Cost Analysis
	Climate change risks & opportunities
Disclosure	General Reporting
	Verification and Validation
	Mandatory Compliance
	Voluntary Disclosure
Futureproofing	Annual Monitoring and Reassessment
	Business Model Integration
	Continual Improvement Process (CIP)
	Measurement, Reporting, and Verification

Whilst Table 2-3 does not encapsulate an exhaustive list of carbon management practices, it outlines those most prevalently adopted in the corporate world. Frameworks for corporate carbon management have been proposed in the literature, offering systematic methodologies for organisations to adopt(Schaltegger and Burritt, 2000; Jeswani, Wehrmeyer and Mulugetta, 2008; Burritt, Schaltegger and Zvezdov, 2011; Tang and Luo, 2014; Wahyuni and Ratnatunga, 2015; Usman Mazhar, 2017; Zhou, 2020b). to provide a systematic methodology from which an organisation can follow.

While there is no universally standardised methodology, Zhou's (2020b) representation in Figure 2-4 outlines a comprehensive carbon management framework to be adopted by organisations. The framework outlines an eight-step process for effective corporate carbon management:

1. **Measurement of Emissions**: Initiating the process, organisations should conduct a carbon accounting exercise employing widely recognised standards (WBCSD and WRI, 2004; WRI and WBCSD, 2011; ISO, 2019b) to establish a baseline for their carbon footprint.
2. **Setting Reduction Targets**: Subsequently, organisations should set ambitious emissions reduction targets in alignment with the latest climate science recommendations, as detailed in section 2.2.4.
3. **Avoidance of Emissions**: This step emphasises behavioural changes within the organisation aimed at preventing emissions from occurring.
4. **Reduction of Emissions**: Focusing on actively implementing energy efficiency measures to reduce carbon emissions.
5. **Switching Energy Sources**: Organisations are encouraged to transition to renewable energy sources instead of reliance on fossil fuels.
6. **Sequestration**: Once direct reduction avenues are exhausted, the framework advises investing in carbon sequestration projects, such as afforestation and reforestation, as intermediate measures.
7. **Carbon Emissions Reassessment**: This stage involves evaluating the residual emissions after implementing the previous steps and understanding the effectiveness of the executed strategies.
8. **Offsetting Residual Emissions**: The final step suggests compensating for residual emissions through credible offsetting schemes to meet the previously set reduction targets.

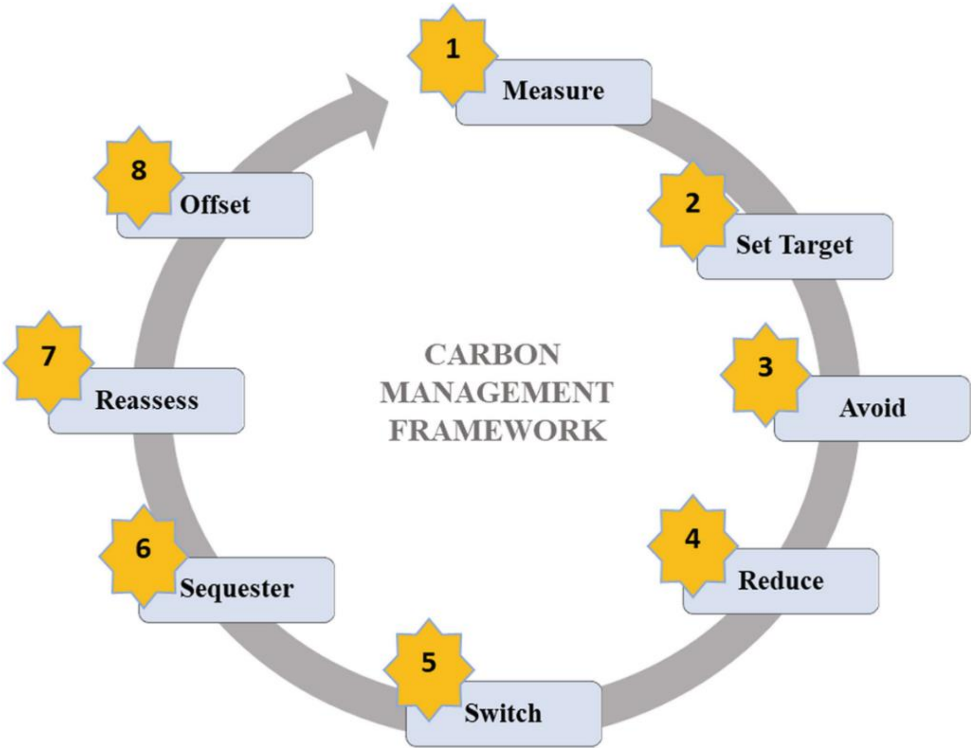

Figure 2-4. Example of a carbon management framework, Source: (Zhou, 2020b)

Zhou's carbon management framework offers a structured, systematic approach that aligns with international standards and underscores the importance of behavioural change in emissions reduction. However, it falls short in addressing the complexity of Scope 3 emissions, lacks specificity in driving behavioural change, and potentially overemphasises sequestration and offsetting, which might divert focus from direct emissions reductions. Additionally, although the figure shows a circular approach, the framework does not stress the necessity for continuous improvement, technological innovation, stakeholder engagement, or adaptation to evolving climate policies. The researcher believes that these areas could be enhanced for a more robust approach to ensure a holistic and dynamic carbon management framework.

2.4.2 Stakeholder Influences on Corporate Carbon Management

This section explores the catalytic role of stakeholders in shaping corporate carbon management practices. Research indicates these practices are not solely motivated by underlying corporate sustainability goals but are significantly shaped by stakeholder pressures (Schaltegger, Hörisch and Freeman, 2017; Almagtome, Khaghaany and Önce, 2020; Seroka-Stolka, 2023). Figure 2-3 illustrates the broad spectrum of stakeholders involved, ranging from internal influences such as employees and investors to external entities such as customers, regulatory bodies, and local communities. This complexity of stakeholders creates a combination of pressures that drive businesses to measure, monitor, and manage their carbon emissions effectively.

Figure 2-5. Key stakeholders influencing businesses across all sectors and sizes.

Regulatory pressures, particularly those from governments, can be considered as pivotal in driving corporate carbon management practices. Governmental policies across the globe are increasing in numbers, especially within the EU and UK (see section 2.2), and require companies to periodically report on carbon emissions to avoid punitive measures. This regulatory landscape emphasises the growing connection between environmental legislation and corporate performance (Trevlopoulos *et al.*, 2021).

The literature further reveals that corporate transparency in carbon management is not merely a regulatory requirement but is becoming a business norm driven by consumer and supply chain expectations (Boukherroub *et al.*, 2017; Yunus, Elijido-Ten and Abhayawansa, 2020; He *et al.*, 2021; Rondoni and Grasso, 2021). With others outlining the type of pressures that each stakeholder group may exert on a business, and the drivers that are derived from such pressure (Henriques and Sadorsky, 1999; Garcés-Ayerbe, Rivera-Torres and Murillo-Luna, 2012; Schaltegger, Hörisch and Freeman, 2017; Lintukangas *et al.*, 2023).

The emergence of environmental, social, and governance (ESG) criteria now plays a crucial role in investing (Seth, Gupta and Gupta, 2021; Macey, 2022). Investors' increasing scrutiny of climate-related risks propels businesses to adopt and report on carbon management practices (Bresnahan *et al.*, 2020). However, Fenwick *et al.* (2022) noted that while ESG reporting is gaining traction among larger corporates, it remains less common among small and medium-sized enterprises (SMEs). Hu and Kee (2022) suggest that many SMEs claim to show some awareness of ESG principles. This could be attributed to various factors, including the incremental costs associated with ESG reporting, a general lack of awareness or understanding of its benefits, and the challenge of limited resources that SMEs frequently encounter (Sommer, 2017).

The literature highlights the relationship between corporate carbon management practices and stakeholder pressures, with government legislation, competitive advantage, and financial incentives as key drivers.

2.4.3 Carbon Accounting & Inventory Management

The first and arguably one of the most critical steps in CM is measuring emissions (Zhou, 2020b), also referred to as carbon accounting and reporting (WBCSD and WRI, 2004). It allows an organisation to understand how carbon is associated with business activities in its operations and the supply chain (WRI and WBCSD, 2011). Carbon accounting is not only seen as a significant step toward tackling climate-related issues but is also of growing interest in the corporate world as it provides economic and social benefits (Stern, 2007; Schaltegger and Csutora, 2012a).

Stechemesser and Guenther (2012) set out to find a comprehensive and detailed definition of 'carbon accounting' through a systematic literature review; their analysis amounted to a differing of opinions depending on the project scale, discussing that projects at a national and global scale are concerned with non-monetary accounting of carbon emissions. In contrast, projects at the organisational scale typically consider both non-monetary and monetary accounting aspects to be necessary. The article summarises with a definition of carbon accounting,

> *"Carbon accounting comprises the recognition, the non-monetary and monetary evaluation and the monitoring of greenhouse gas emissions on all levels of the value chain and the recognition, evaluation and monitoring of the effects of these emissions on the carbon cycle of ecosystems."*- (Stechemesser and Guenther, 2012)

For this thesis, the focus is narrowed to the corporate and business levels of carbon accounting. More specifically, an interest in the availability, applicability, and accessibility of carbon management practices as applied to small and medium-sized enterprises (SMEs). This section of the review focuses on voluntary accounting and inventory reporting. Due to the lack of regulations applied to SMEs, most CM projects are undertaken voluntarily and, therefore, are not required to follow a standard procedure or reporting guideline. This lack of regulation can complicate choosing the most suitable methodology for a business with minimal resources and knowledge.

Whilst there are numerous frameworks, methods, and standards available for carbon accounting, the 'Greenhouse Gas Protocol': Corporate Standard' and 'ISO 14064' are the most widely used international methodologies available(Bhatia and Ranganathan, 2011; Schaltegger and Csutora, 2012a; Gibassier and Schaltegger, 2015; Smith, 2016; Zhou, 2020a), and have become the de facto standards for carbon accounting and reporting at a corporate and project level (Ascui and Lovell, 2012).

2.4.3.1 The Greenhouse Gas Protocol

In the late 1990s, the World Building Council for Sustainable Development (WBCSD) and the World Resources Institute (WRI) recognised the need for an internationally established standard for corporate GHG accounting and reporting. In 2001, the first edition of the GHG Protocol was published. Since then, the original corporate standard has been updated along with several additional publications and a suite of calculation tools to assist companies in accounting for their GHG emissions, in addition to helping to measure the benefits of carbon reduction and mitigation projects (WBCSD and WRI, 2004; WRI and WBCSD, 2011; Sotos, 2015).

The Greenhouse Gas Protocol is the most widely adopted standard for corporate organisations to measure and manage their greenhouse gas emissions. It provides a standardised, comprehensive, and moderately flexible process across businesses in the private and public sectors. Despite its strengths, several issues persist, such as the complexity of implementation, particularly for SMEs (Abrahamsson, Mahapatra and Lerman, 2022), and the difficulties in accurately accounting for Scope 3 emissions (Green, 2010). Furthermore, while it guides measurement and reporting, the GHG Protocol could enhance its provisions for driving emissions reductions and evolve to align with emerging technologies and international climate goals (Hickmann, 2017; Tsai *et al.*, 2023). The researcher believes that by addressing these limitations through simplifying the process for smaller entities, refining Scope 3 assessments, and incentivising reduction efforts, the GHG Protocol could help increase engagement in corporate carbon management, especially among SMEs. As of 2023, the GHG Protocol is undergoing a process of revisions. A feedback survey was conducted between November 2022 and March 2023 to gain opinions and suggestions from the public on developing updates and new additional guidance (WRI and WBCSD, 2023).

Carbon accounting considers many metrics and measures that define a project and eventually ensure that specific goals and targets are met as per user requirements Table 2-4 compiles the metrics and measures outlined throughout the varying standards from the GHG Protocol to present the typical steps considered in accounting for carbon emissions at a corporate level.

Table 2-4. Carbon Accounting Metrics & Measures (Adapted from The GHG Protocol)

Accounting Stage	Metric/Measure	Description
Defining Boundaries	Organisational Boundaries	Two common approaches define organisational boundaries: ▪ <u>Equity Share approach:</u> the organisation accounts for emissions from operations based on its share of equity in the organisation. ▪ <u>Control approach:</u> the organisation accounts for 100% of emissions from operations over which it has control (WBCSD and WRI, 2004). Control can either be defined in financial or operational terms.
	Operational Boundaries	Defining the operational boundaries determines the direct and indirect emissions to be included within an

		assessment; three scopes are used to define operational boundaries: ▪ Scope 1: Direct GHG emissions – from sources that are owned or controlled by the company (WBCSD and WRI, 2004) ▪ Scope 2: Indirect GHG emissions – from the generation of purchased electricity consumed by the company (WBCSD and WRI, 2004) ▪ Scope 3: Other indirect GHG emissions not covered under Scope 2 – An optional reporting category that accounts for all other indirect emissions (WBCSD and WRI, 2004)
Quantifying Emissions	Activity Data / Data Collection	Collecting activity data for an organisation is an essential step in carbon accounting. It allows for disaggregation of the energy used and helps to identify high-usage business activities. Once energy data has been collected and disaggregated, emissions can be calculated to create an organisation's carbon footprint.
	Scope 1 Emissions	Includes emissions produced directly from business activities. E.g., Emissions produced from combustion in owned or controlled boilers, furnaces, gas-fuelled cooking equipment and vehicles. Typically, a mandatory reporting scope.
	Scope 2 Emissions	Accounts for indirect emissions that occur because of using purchased electricity to power equipment, machinery, and lighting etc. within the organisational boundary defined. E.g., Electricity used *onsite* that has been purchased from the national grid system. Typically, a mandatory reporting scope.
	Scope 3 Emissions	Includes all other indirect emissions. Generally, accounts for the largest portion of emissions from an organisations activity and typically comprises of supply chain emissions, business travel, waste management, employee commuting, transportation, and distribution (T&D), end-of-life treatment of sold products, leased assets, franchises, and investments (UKGBC, 2019a). Typically, an optional reporting scope.

Tracking Emissions	Establishing a Baseline	To track progress, it is essential to set a "base year" or "base period" as a benchmark from which to measure against. Typically, a calendar year is chosen, however, this may include any 12-month period depending on available data. This enables an organisation to set specific temporal targets.
	Updating the Baseline	The GHG Protocol and ISO standard recommend developing a 'baseline recalculation policy' to account for any potential changes including: ▪ Structural changes in the organisation ▪ Changes in calculation methodology or improvements in accuracy of emissions factors ▪ Discovery of a substantial error or a number of cumulative errors
Inventory Management	Inventory Quality Management	A useful, but often neglected, measure of carbon accounting. Requires an organisation to assess the quality of data that has contributed to the final carbon footprint. The goal is to limit the possibility of any accounting errors.
	Verification & Validation	Related to "Inventory Quality Management" but a comprehensive metric. It is not a required step in carbon accounting but is recommended for more complex and in-depth inventories. Helps to avoid inaccurate reports and demonstrates that the data presented is transparent, reliable and robust. It does, however, cost to verify and/or validate an organisation emission and is often omitted from studies to avoid extra costs.
	Reporting Techniques	The principles set out in both the GHG Protocol and ISO 14064 are regularly referred to when reporting on carbon emissions for an organisation. The following is typically reported: ▪ Description of the company and inventory boundary ▪ Information on emissions ▪ Optional information, including information on emissions and performance, and offsets.

Voluntary carbon accounting is becoming an increasingly popular practice at the corporate level, displaying an abundance of benefits to companies worldwide. In a testament to this trend, over 5,000 companies disclosed their annual emissions data to the Carbon Disclosure Project (CDP), a leading environmental non-profit organisation, in 2019 alone (CDP, 2019). Furthermore, of the world's largest 250 corporations, 92% reported their sustainability performance to the Global Reporting Initiative (GRI), with over 62,000 sustainability reports recorded in the GRI database (GRI, 2020). These figures demonstrate the increasing number of companies choosing to report on climate-related and sustainability issues.

Motivations for this surge in reporting vary widely from drawing the attention of eco-conscious investors (Smith, 2016) to responding to the intense public scrutiny of industries with substantial carbon emissions, such as the maritime and aviation industries (Wolf and Abbugao, 2019). Whatever the reason, progressively more companies are deciding to embark on the journey toward becoming more sustainable and reducing their carbon impact.

Despite this evident upsurge among larger corporations, small and medium-sized enterprises (SMEs) lag in measuring, reporting, and disclosing their carbon emissions (Vickers *et al.*, 2009; Conway, 2015b). This presents a challenge and an opportunity for growth and leadership in carbon management practices within the remit of SMEs.

2.5 Part 1 Summary

Part 1 of this review was designed to explore the literature behind climate policy and the development of carbon management practices at national and corporate levels. The purpose was to establish a solid grounding for the state of development in carbon management and to provide an overarching view of the most relevant literature within the field. The review also aimed to identify the gap between academic, peer-reviewed literature and standard industry practices to provide a window of opportunity for further research. A narrative review was conducted assessing literature in the following areas:

- The history of climate policy over the last four decades
- The UK's approach to climate policy
- The UK's contribution to climate change adaptation and mitigation
- Typical carbon management practices (CMPs) are used at national and corporate level.

Each area has been evaluated to understand which aspects of carbon management need to be improved in rigorous and in-depth research studies. The literature review has highlighted a significant gap in understanding how UK climate policy intersects with corporate carbon management practices, particularly within SMEs. This gap has led to the formulation of the following hypothesis:

> *A lack of academic research seems to exist when considering carbon management as a tool for climate change mitigation within UK-based SMEs.*

From this hypothesis, the following research questions were suggested as an initial observation:

- *To what extent has the relationship between carbon management and SMEs been reported in academic and grey literature?*
- *Are there any practical applications of SMEs implementing carbon management practices within academic literature?*
- *Can existing corporate carbon management practices be adapted and integrated into business models of small and medium-sized enterprises (SMEs) to support and encourage emissions reduction?*
- *How will applying such practices impact anthropogenic greenhouse gas (GHG) emissions in the United Kingdom?*

To address these questions, a systematic literature review was conducted to analyse academic and peer-reviewed publications and identify any existing knowledge gaps. This methodical approach ensures minimal redundancy in research efforts and contributes to building a robust database of information in the field.

Part 2: The Role of Carbon Management in SMEs: a systematic review

2.6 Systematic Literature Review Methodology

This section will briefly outline the methods used to perform the systematic literature review, including the search strategy, inclusion and exclusion criteria, screening and selection of data, data extraction, quality assessment, and data analysis.

2.6.1 Search strategy

The search strategy used to perform the review included a combination of academic published literature (e.g., journal articles or conference proceedings) and grey literature (e.g., government reports, energy magazines/websites), comprising three key stages:

Stage (1) A preliminary limited search of 2 key databases: 'Environment Complete' and 'Business Source', to identify relevant keywords in the title and abstract.

Stage (2) Terms and keywords identified as in Stage One and the synonyms used by respective databases were used in a comprehensive literature search.

Stage (3) Refinement and data synthesis

2.6.2 Search Terms

The initial search terms used in Stage (1) can be found in Table 2-5 under the fields "business size" and "environmental metric"; this provided a basis from which further terms were identified.

Table 2-5. A List of Search Terms for the Systematic Literature Review

Field/Topic	Search Terms Used	Search Location
Business Size	"Small and medium sized enterprises" OR "SME" OR "SMEs" OR "small business" OR "small companies" OR "small company" OR "small enterprise" OR "medium enterprise"	Title, Abstract
Environmental Metric	"Carbon management" OR "climate policy" OR "carbon accounting" OR "emissions" OR “climate change”	Title, Abstract
Specific Keyword Search	"Carbon emissions" OR "CO_2 emissions" OR "CO_2e" OR "carbon reduction" OR "carbon footprint" OR "greenhouse gas" OR "GHG" OR "climate change" OR "carbon reduction strategies" OR "climate mitigation" OR "energy use" OR "energy efficiency" OR "United Kingdom" OR "UK"	All Text
Individual Words Considered	Carbon / Energy / GHG / Climate / SME / Anthropogenic / Renewable / Bioenergy / Emissions / Operational / Whole life	Subject Terms

2.6.2.1 Example Search String

("small and medium sized enterprises" OR "SME") AND ("carbon management" OR "carbon accounting")

2.6.3 Search Databases

Search databases (see Table 2-6) have been selected based on relevance to the review and availability to the researcher. Databases have been identified through the University of Liverpool Database Library.

Table 2-6. Search Databases for Systematic Literature Review

Field/Topic	Database(s)
Environment	Environment Complete
Business	Business Source Complete, Sage Business Cases
General (multidisciplinary)	Science Direct, Scopus, Web of Science, Google Scholar, eBooks (EBSCO)
Journal, Book, and Thesis	Cambridge Core, JSTOR, EThOS, OATD
Grey Literature	Economist, OpenSIGLE, Google Search

2.6.4 Inclusion Criteria

The review included all articles published in the last 20 years in English, found within the databases listed in Table 2-6. Complete copies of articles identified through the search terms found in the title or abstract and meeting the inclusion criteria were obtained for data synthesis. When searching reference lists and bibliographies, articles found were considered based on their title and abstract.

2.6.4.1 Context

The review considered all studies that consider small and medium-sized enterprises (SMEs) as the primary research focus, whether a specific case study or a generalised study. Articles that only briefly mention SMEs, with a stronger focus on corporate companies, were excluded.

2.6.4.2 Types of Intervention

The interventions related to adapting, integrating, and applying corporate carbon management practices to smaller companies. The corporate carbon management (CM) practices included in this study relate to company policy, measurement, and verification (M&V), inventory and risk management, business strategies (including financial metrics), monitoring, and disclosure.

2.6.4.3 Outcome Measures Eligible

All eligible studies considered the need to increase the uptake of SMEs engaging in carbon management to reduce emissions. Alternatively, eligible studies demonstrated the current problem by highlighting the contrast between the maturity of carbon management in corporate firms and those in smaller companies.

2.6.4.4 Types of Studies

All studies evaluating and indicating the relationship between SMEs and carbon management were included in this study, including qualitative, quantitative, and mixed research methods. If no studies of this type are available, those that discuss SMEs and their approach to carbon emissions and climate change mitigation were considered.

2.6.5 Screening and Selection

Rayyan®, a software designed to help screen and select studies for systematic reviews, was used for screening studies. First, all articles were screened at the abstract and title level, following which full-text versions were obtained and reviewed at a high level, subject to meeting the inclusion criteria. Articles not meeting the inclusion criteria were removed. The remaining full-text articles were then subjected to a full review, applying the exclusion criteria set out in Table 2-7 to filter any unsuitable papers remaining.

2.6.5.1 Exclusion Criteria

Table 2-7. Systematic Literature Review Exclusion Criteria

EC#	Description
EC1	The selected article is not written in English
EC2	The article is a short paper (less than four pages)
EC3	The focus of the paper is not primarily concerned with SMEs
EC4	The article does not contain original data relevant to the inclusion criteria

2.6.6 Data extraction

Data extraction was then performed in Rayyan® using filtered data fields to collect information on study design, methodology, results, and future work suggestions (if any). The data extraction results were collated into Mendeley®, a reference management software. For the selected articles with missing data, an attempt to contact the original author was made to obtain missing data considered crucial to the systematic literature review.

The meta-data collected for each paper includes (i) title, (ii) authors, (iii) publication year, (iv) publication location (i.e., journal name), (v) type of publication, (vi) study design, (vii) methodology (viii) results and future work.

2.6.7 Quality assessment

Quality assessment (QA) addresses any bias and internal and external validity (Kitchenham and Charters, 2007). Three main quality issues were considered when evaluating the articles identified in the review: Rigour, Credibility, and Relevance. Criteria proposed by Dybå and Dingsøyr (2008) are used to perform the quality assessment and are shown in Table 2-8.

Table 2-8. Quality Criteria (Dybå and Dingsøyr, 2008)

QC#	QA Question
QC1	Is the paper based on research (or is it merely a “lessons learned” report based on expert opinion)?
QC2	Is there a clear statement of the aims of the research?
QC3	Is there an adequate description of the context in which the research was conducted?
QC4	Was the research design appropriate to address the aims of the research?
QC5	Was the recruitment strategy appropriate to the aims of the research?
QC6	Was there a control group with which to compare treatments?
QC7	Was the data collected in a way that addressed the research issue?
QC8	Was the data analysis sufficiently rigorous?
QC9	Has the relationship between the researcher and participants been considered adequately?
QA10	Is there a clear statement of findings?
QA11	Is the study of value for research or practice?

2.6.8 Data Synthesis

Meta-ethnographic methods were used to synthesise the data extracted from the primary studies (W. Noblit and Dwight Hare, 1988). The first stage of data synthesis involved identifying the key concepts from each study using the author's original terms. Key concepts are then inputted into a table whereby a comparison can occur, and common findings can be grouped. Once the data is organised, analysis of the common findings should determine the current state of the literature, from which gaps can be identified for future work. Meta-ethnographic synthesis involves relating studies in one of three ways: they may be directly comparable as reciprocal translations; they may stand in opposition to one another as refutational translations; or taken together, they may represent a line of argument (Britten *et* *al.*, 2002). Noblit and Hare (1988) outlined a seven-step process for conducting a meta-ethnography, shown in Table 2-9.

Table 2-9. Seven phases for conducting meta-ethnography (W. Noblit and Dwight Hare, 1988)

Phase	Description
1	Getting started
2	Deciding what is relevant to the initial interest
3	Reading the studies
4	Determining how the studies are related
5	Translating the studies into one another
6	Synthesising translations
7	Expressing the synthesis

2.7 Systematic Literature Review Findings

Results from the systematic literature review can be found in Appendix A, with this section highlighting the key findings.

2.7.1 Search Stage 1 – Preliminary Limited Search

The preliminary limited search (search Stage 1) focused on identifying the keywords used. The search was limited by design and found 19 articles that fit within the scope of the search criteria. 12 articles were found in the Environment Complete database, all of which were from academic literature, and 7 were found in the Business Complete database, 5 from academic literature and 2 from grey literature.

This initial search was used to examine the keywords within the articles found; this process helped identify whether any keywords needed to be added to the initial methodology set out. The following keywords were identified as potentially relevant. The ones highlighted in bold were added to the Stage 2 search strategy, while the others were acknowledged for further assessment.

"life cycle assessment" OR "eco-design" OR "**energy management**" OR "sustainability" OR "**carbon intensity**" OR "**CO2 emissions**" OR "**CO2**" OR "**low-carbon**" OR "**energy saving**" OR "environmental" OR "pollution"

2.7.2 Stage 2 – Main Search

Stage 2 involved a comprehensive search of 13 databases. The search returned 660 articles, with 534 and 126 representing academic and grey literature, respectively. Table 2-10 shows the number of articles found in each database.

Table 2-10. Systematic Literature Review Stage 2 Search Findings

Database	Academic Literature	Grey Literature
Environment Complete	64	3
Business Source Complete	87	93
ebooks (EBSCO)	46	0
eThOS	18	0
Google Scholar	99	0
Google Search	9	0
JSTOR	47	0
OATD	11	0
Sage Publications	16	0
Science Direct	58	0
Scopus	40	24
Uni of Liverpool Library	19	0
Web of Science	20	6

The data was then run through Rayyan software to identify and remove any duplicates before applying the inclusion criteria and screening. This resulted in 570 articles, with 468 academic articles and 102 grey articles. Once duplicates were removed, Rayyan was once again utilised to support the initial phase of screening through the application of the inclusion criteria.

Once this initial screening phase was complete, 149 articles remained. The next step involved a second wave of screening to validate that all articles remaining met the inclusion criteria. Additionally, the exclusion criteria were applied to filter any articles that did not meet the research scope. The final screening process resulted in 116 articles, all demonstrating some form of relationship between carbon management practices and SMEs.

2.7.3 Stage 3 - Refinement and data synthesis

Stage 2 identified 116 articles that met the inclusion criteria in section 2.6.4. All articles mentioned SMEs with similar keywords in the title or abstract. The final stage involved refinement to identify which articles were wholly material to the study and would help answer the initial research questions. This process involved a more rigorous approach to reviewing the articles but was still concerned only with the title and abstract.

Several keywords were identified as potentially relevant to the research and appeared frequently within titles and abstracts, shown in Table 2-11. Figure 2-6 shows the frequency of these keywords[3] within the title and abstract of the article and highlights how prominent the concepts of 'energy' and 'carbon' are within the articles found. However, the researcher thought that the search was still too broad. Further refinement was required to prove the hypothesis from the narrative literature review in part 1 of this chapter.

Table 2-11. Systematic Literature Review Keywords - Primary and Secondary

Primary Keyword	Secondary Keyword
Energy	Energy management, energy efficiency, energy audit, energy savings, energy optimisation, energy-intensive, energy conservation, energy consumption
Environment	Environmental impact, environmental demands, environmental sustainability, environmental footprint, environmental performance, environmental policies
Sustainability	Sustainable design, sustainable practices, sustainability footprints, sustainable growth, sustainability performance
Carbon	Emissions, greenhouse gas, GHG, CO2, carbon footprint, low-carbon, carbon accounting, climate change, carbon management, global warming, life-cycle assessments, carbon modelling
Green	Green energy, green business

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[3] *Keywords presented in Figure 2-6 include searches of all primary and secondary keywords.*

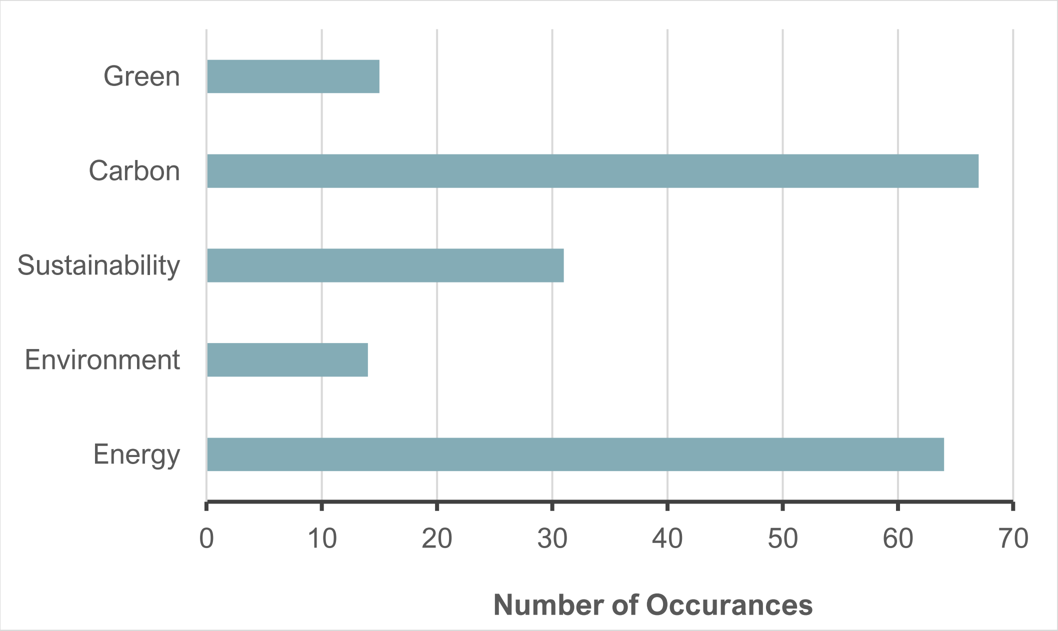

Figure 2-6. Systematic Literature Review: Keywords in Title & Abstract

At this stage, it was vital to revisit the hypothesis guiding the systematic literature review,

> *A lack of academic research seems to exist when considering carbon management as a tool for climate change mitigation within UK-based SMEs.*

To further narrow the search, all keywords (primary and secondary) for both 'carbon' and 'SMEs' were applied to the article titles and abstracts, helping to identify the most pertinent studies. Results from this final level of refinements gave 57 studies that mentioned the relationship between 'carbon' and the associated keywords and SMEs.

2.8 Small and Medium-Sized Enterprises (SMEs) and Carbon Management: A Brief Review

Carbon management has gained increasing attention in recent years due to the growing awareness of the environmental impacts of carbon emissions (Zhou, 2020b). Small and Medium-sized Enterprises (SMEs) play an essential role in economic growth and development. However, their environmental impacts and contribution to carbon emissions have yet to be studied. This brief review explores the role of carbon management in SMEs and the potential impact on national emissions.

2.8.1 Drivers of Carbon Management in SMEs

According to Hendrichs and Busch (2012b), carbon management in SMEs involves identifying, measuring, and reducing carbon emissions associated with business operations. SMEs have been identified as a substantial contributor to UK carbon emissions (Conway, 2015c; Meng *et al.*, 2018), accounting for an estimated 43-53% from businesses and around 29-36% of the UK's total emissions (British Business Bank, 2021). Several studies have explored the potential benefits of carbon management in SMEs, including cost savings, enhanced reputation, and improved environmental performance (Bradford and Fraser, 2008; Bhattacharyya Sarkar and Manoharan, 2009; Hendrichs and Busch, 2012b; Conway, 2015c; Yao, Huang and Song, 2019)

2.8.2 Barriers to Carbon Management in SMEs

Despite the potential benefits, SMEs need help implementing carbon management practices. These barriers include lack of knowledge and expertise, limited financial resources, and the perception that environmental initiatives are not a priority(Hendrichs and Busch, 2012b; Trianni, Cagno and Farnè, 2014; Meath, Linnenluecke and Griffiths, 2016a). Additionally, regulatory frameworks and government policies may not adequately support SMEs implementing carbon management practices. SMEs often lack the expertise and resources to effectively implement carbon management practices (Conway, 2015c). In addition, many SMEs are concerned about the potential costs of implementing carbon management practices and are hesitant to make significant investments in climate mitigation initiatives (Dayaratne and Gunawardana, 2015; Meath, Linnenluecke and Griffiths, 2016b; British Chamber of Commerce, 2021).

In the researcher's opinion, SMEs would benefit from a more tailored approach to carbon reduction and mitigation due to the diversity of sectors they cover and the various company sizes. SMEs cover a broad range of sizes, from micro entities with three employees to medium-sized organisations with two hundred employees (BEIS, 2023a). A more specific, careful approach must be applied when dealing with SMEs, being able to address the same problems faced by large corporates, cities, and nations but on a smaller, more relatable scale. The researcher believes that further research is required into the barriers within SMEs; this is addressed throughout Chapter Four, where a focus group explores the limitations, barriers, drivers, and more.

2.8.3 Carbon Management Methodologies for SMEs:

Several carbon management methodologies have been developed to assist businesses in reducing their carbon emissions. Whilst not explicitly designed for SMEs, these methodologies and tools could be applicable to an SME looking to measure and reduce its carbon impact. Some of the more common methodologies are mentioned below, briefly reviewing their applicability for smaller businesses.

1. **The Greenhouse Gas Protocol** is the most widely used methodology for calculating and reporting GHG emissions, providing guidance on how to measure emissions from different sources, such as energy use, transportation, and waste (WBCSD and WRI, 2004). Although companies across the spectrum utilise this protocol to track and report their carbon footprint, the researcher believes the standards could be refined for clarity. The current guidance, while robust, may pose complexities, particularly for larger organisations and even more so for smaller enterprises (SMEs).
2. **ISO 14064** is an internationally recognised greenhouse gas (GHG) accounting and verification standard. It provides a framework for organisations to quantify and report their GHG emissions and removals and to track their progress over time (ISO, 2019a). However, the process can be complex for small businesses and is typically used by many larger companies and governments.
3. **The Carbon Trust Standard** is a certification that recognises organisations for their efforts to reduce carbon emissions. To achieve the certification, SMEs must measure their carbon footprint, set targets for emissions

reduction, and implement initiatives to achieve those targets. The certification is renewable every two years, encouraging ongoing progress; however, this approach can seem daunting to an SME who may lack the required knowledge.

4. **PAS 2060** is a standard for carbon neutrality. It provides guidelines for organisations to achieve carbon neutrality by balancing GHG emissions with verified carbon offsets or removals. This standard is not widely used and has received criticism for its offsetting approach.

Overall, several carbon management methodologies are available to SMEs, each with its strengths and weaknesses; however, the critical theme amongst them is the complexity and detail required. This is foreseen as one of the most common pitfalls when attempting to engage SMEs in carbon management(Moss, Lambert and Rennie, 2008; Conway, 2015c). Furthermore, existing research suggests that SMEs often face challenges in adopting and implementing generalised frameworks and methodologies for environmental reporting, suggesting that a sector-specific approach might be more effective in engaging smaller firms in such practices (Hillary, 2004; Burke and Gaughran, 2006; Alromaizan *et al.*, 2023).

2.9 Development of Research Questions

The following research questions have been deducted from the research conducted throughout this chapter:

RQ 1. How do SMEs perceive carbon management practices within their business, and what is the extent of individual employees' knowledge in this field?

RQ 2. Can a generalised framework support UK-based SMEs in reducing their operational carbon impact, adapting techniques currently found at global, national, and corporate levels?

RQ 3. Can a UK-based SME achieve net-zero operational emissions at net-zero cost?

RQ 4. Would the practice of carbon management in SMEs provide a great enough impact on national emissions to necessitate action from the UK Government?

2.10 Chapter Summary

In conclusion, carbon management and the related practices (refer to section 2.4) are of great importance to achieving the UK 2050 net-zero target (UK Government, 2008b; Castle and Hendry, 2023). This review identified some of the significant flaws of current government policy (see section 2.3.3) and the lack of acknowledgement for SMEs when accounting for UK-wide business emissions (Mole and Belt, 2023). SMEs account for 99.9% of all registered businesses in the UK, contributing to over 50% of the nation's turnover, as shown in Figure 2-7 (DBT, 2023)and approximately 29-36% of the UK’s total emissions (British Business Bank, 2021). These statistics highlight the significance of SMEs should the UK wish to find pragmatic solutions to reducing the nation's emissions.

The potential benefits of carbon management in SMEs include cost savings, enhanced reputation, and improved financial performance (Conway, 2015b; Hoogendoorn, Guerra and van der Zwan, 2015b); however, SMEs face several barriers to implementing carbon management practices, including lack of knowledge, limited financial resources, and the perception that environmental initiatives are not a priority (Hendrichs and Busch, 2012c; Conway, 2015b; British Chamber of Commerce, 2021). To support SMEs in implementing carbon management practices, the researcher believes that the UK government's policies must be enhanced to consider potential solutions for reducing business emissions. The researcher also believes that more specific guidance and frameworks should be developed to provide SMEs with a relatable and actionable process that will encourage innovation and help mitigate climate change's negative impacts. The research conducted throughout this thesis addresses some of these barriers by developing a framework focusing on carbon management within SMEs and, more specifically, medium-sized organisations[4], identifying areas where they can reduce their carbon impact and providing guidance on implementing these changes.

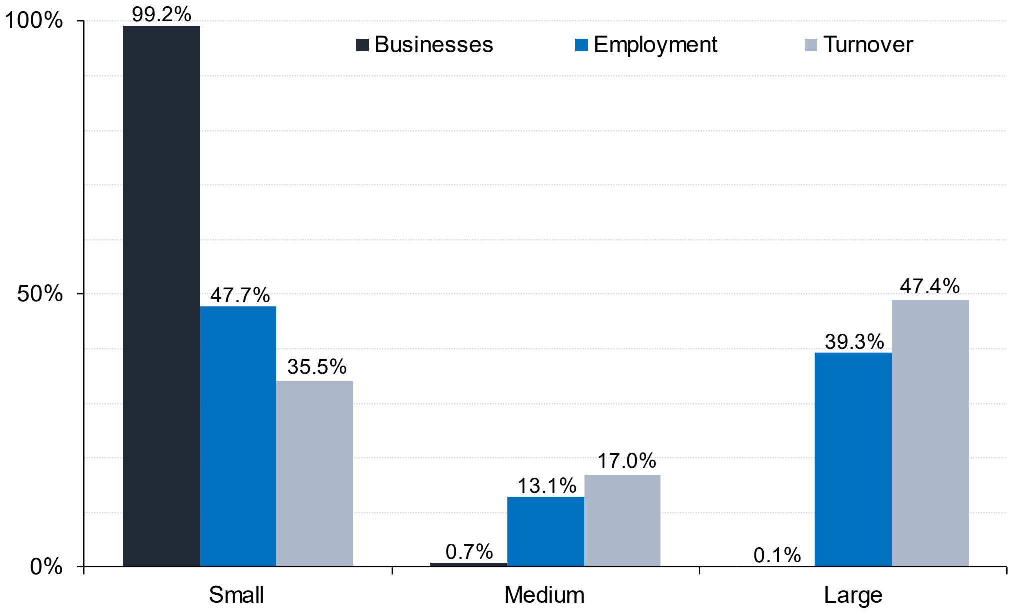

Figure 2-7. Contribution of different sized businesses to total population, employment, and turnover, start of 2023 (DBT, 2023)

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[4] *Medium-sized organisations are defined in the UK by any organisation with between 50-250 employees, of which there are 36,900 (as of October 2023)* (DBT, 2023).

CHAPTER THREE

3. Research Methodology

3.1 Chapter Overview

This chapter defines the research methodology, including the chosen research design and how it could address the research questions and objectives set out in the preceding chapters. As discussed in 'Chapter One: Introduction', the structure of this thesis does not follow the conventional thesis structure. This deviation in the thesis structure is attributed to the mixed-methods research design implemented (introduced in section 3.2 and rationale explained in section 3.3); this prompted the researcher to adopt an unconventional thesis structure that more aptly accommodates the work. The research was conducted in two primary studies, with the development of a novel framework occurring between the two (refer to section 3.2 for more information). As a result, detailed methodologies for each study are outlined in the following chapters (see chapters 4, 5, and 6), and this chapter is dedicated to explaining and justifying the methods chosen. The philosophical approach that inspired the research design is discussed (refer to section 3.3, providing the foundations and justifications for the chosen methods.

As identified in Chapter Two, the researcher believes that significant areas of carbon reduction methodologies are yet to be dealt with, particularly when addressing SMEs in the UK. Addressing this problem is the research's primary focus and driver for developing a novel carbon management (CM) framework. The CM framework aims to address the key issues UK SMEs face when tackling their operational carbon emissions. The following chapter explains the research methods adopted and includes discussions around the following:

- An overview of research design - including the research design framework
- The rationale for using a mixed-method approach.
- The chosen research design – including the inherent strengths and weaknesses.
- Ethical considerations and the procedure to address potential ethical issues.

3.2 Research Design

This section describes the research design used throughout this thesis, detailing the overarching strategy that guided the integration of the study's various components. The research design formulation was pivotal in ensuring a structured and logical approach, crucial for effectively tackling the research questions. Additionally, the design's systematic characteristics are intended to facilitate reproducibility, an essential aspect for future studies building on this work.

This thesis does not follow the conventional methods of research that rely exclusively on either qualitative or quantitative methods; instead, a mixed-methods approach was taken (discussed later in section 3.3). This approach utilises qualitative and quantitative research strengths, providing a more comprehensive understanding of the research problem.

3.2.1 Research Sponsor and Industrial Partner

This research was sponsored by **Knowsley Safari**, a UK zoological safari park, which initiated a request to the university for scholarly research to identify strategies to reduce their emissions. Knowsley Safari operates a diverse range of facilities, including several animal habitats and enclosures, an amusement park, multiple on-site food outlets, administrative offices, an auditorium, and a conference centre, all situated within an expansive nature reserve. Classified as a medium-sized enterprise within the Arts, Entertainment, and Recreation sector according to the UK Government's Standard Industrial Classification (SIC), Knowsley Safari's collaboration provided a comprehensive longitudinal case study that shaped the research design. This partnership offered a practical and applied approach to the research, allowing for the investigation of a real-world issue through an academic lens.

3.2.2 John Dewey’s Five-Step Model of Inquiry

The theoretical foundation for this research draws upon 'Dewey's Five-Step Model of Inquiry,' as illustrated in Figure 3-1. John Dewey, a renowned philosopher, promoted the belief that learning is most effective when practical and that a pragmatic approach is essential when addressing problems (Morgan, 2014a; Hildebrand, 2018). This pragmatic and empirical philosophy profoundly influenced the development of the research methodology for this thesis.

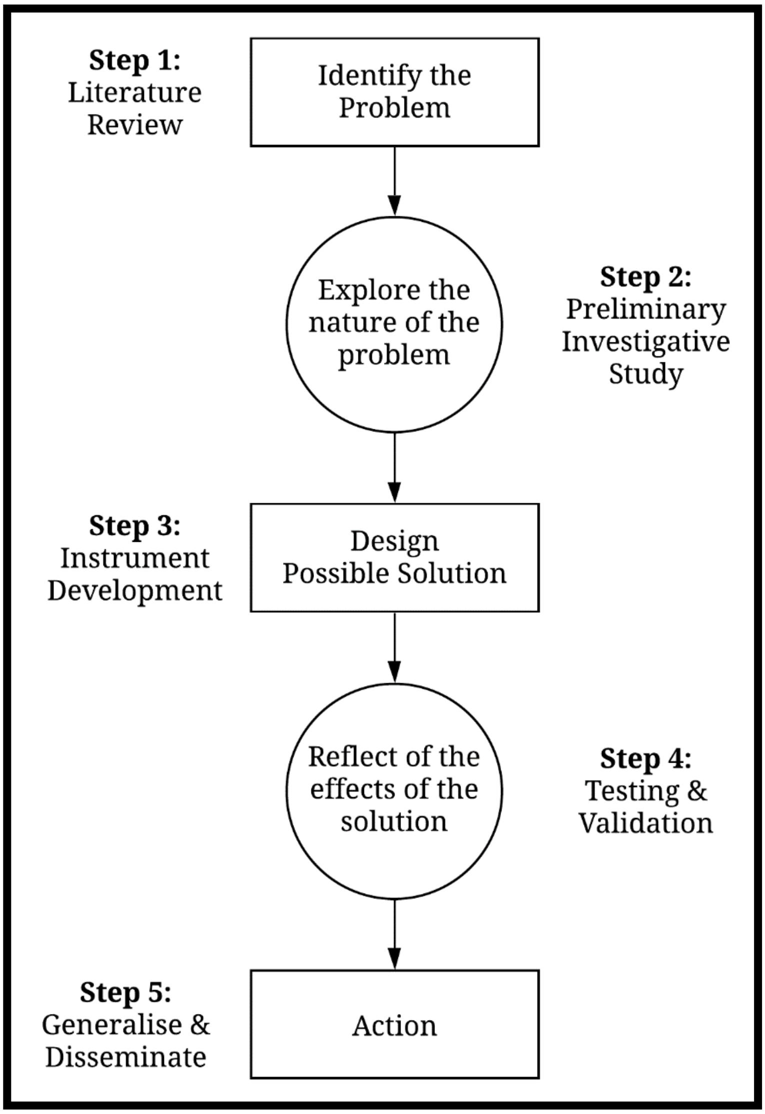


Figure 3-1. John Dewey's Five-Step Model of Inquiry – adapted to fit within the scope of this thesis (Morgan, 2014a)

As with Dewey's model, depicted in Figure 3-1, the research was designed as a five-step process. Each step is pragmatically structured to address the research problem systematically:

Step 1: Identify the Problem – This step was accomplished through an extensive literature review of existing methodologies and frameworks to support SMEs in undertaking carbon management practices, as detailed in Chapter 2.

Step 2: Explore the Nature of the Problem – This involved discussing the problem and exploring potential solutions via a preliminary investigative study in Chapter 4. A focus group was convened to explore the problem, examine ideas, and refine the research scope.

Step 3: Design Possible Solution – The creation of a carbon management framework, described in Chapter 5, was undertaken to offer a pragmatic solution to the issues identified during the preceding steps.

Step 4: Reflect on the Effects of the Solution – A quantitative field study designed to evaluate the proposed framework's efficacy was conducted and discussed in Chapter 6.

Step 5: Action - The final step involved applying the developed framework to a real-world scenario, also examined in Chapter 6. This stage was crucial for validating the framework ensuring practicality if applied to a business.

3.2.3 Research Design Framework

Figure 3-2 presents the research design framework utilised in this thesis.

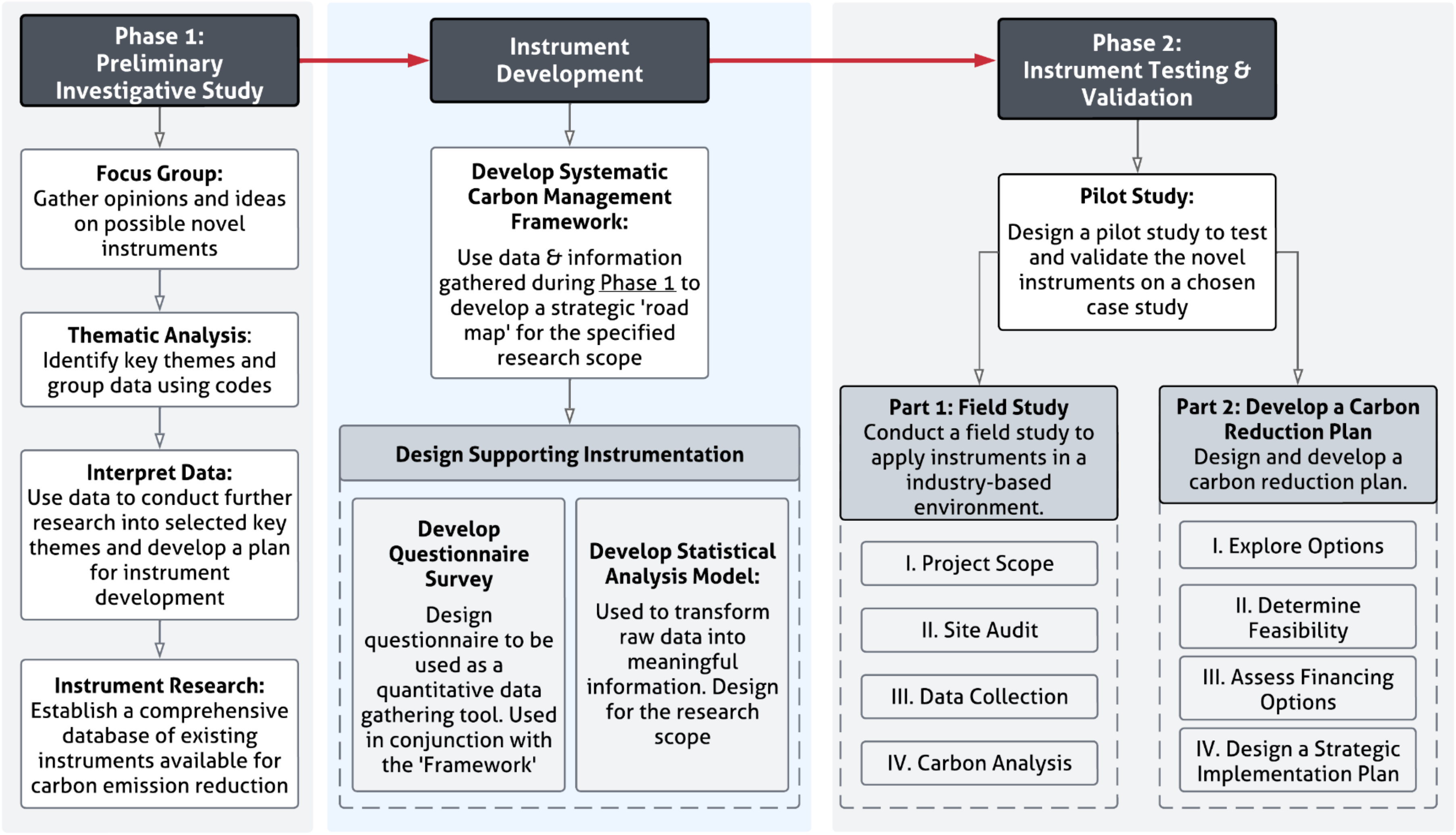


Figure 3-2 Research Design Framework

3.2.3.1 Phase 1: Preliminary Investigative Study

In Phase 1, detailed in Chapter 4, a qualitative preliminary investigative study was undertaken to understand the operational subtleties of a typical UK SME. This exploratory phase comprised the more extensive longitudinal case study conducted in partnership with Knowsley Safari. It was instrumental in laying the groundwork for the subsequent development of research framework.

A focus group, selected as the primary data collection tool (justified in section 4.3 and the full methodology is outlined in Chapter 4), was complemented by a series of informal interviews with Knowsley Safari employees. Both methods provided rich, qualitative insights into the day-to-day workings of an SME. The detailed methodology and findings from these discussions are thoroughly explored throughout Chapter 4.

Thematic analysis was utilised to analyse the data gathered from the focus group. This method facilitated extracting and interpreting salient themes, which served as a foundation for developing a carbon management framework. The rationale for employing thematic analysis is substantiated in Section 4.3.4

The findings from this phase were crucial in identifying operational barriers specific to SMEs and instrumental in pinpointing practical, applicable solutions. In turn, these findings supplemented the foundational literature review in Chapter 2, creating a cohesive narrative that bridges theory and practice within the scope of SME operations.

3.2.3.2 Framework Development

In response to insights gained from the initial qualitative study, it became evident that a novel approach was required to address the challenges presented by the industrial partner. As a result, a framework was developed, to thoroughly address the research problem and facilitate the implementation of carbon reduction strategies. The creation and evolution of this framework is exhaustively detailed in Chapter 5.

3.2.3.3 Phase 2: Framework Testing

The creation of the carbon management framework necessitated rigorous testing to ensure their validity. A case study was conducted within the operational setting of the industrial research partner, Knowsley Safari, providing a practical context for trial and assessment. This setting offered an opportunity to acquire immediate and insightful feedback from the stakeholders involved in the project. The details of this quantitative testing phase are thoroughly explained in Chapter 6, encompassing both a field study and a desk-based research and development study.

The field study (outlined in Section 6.3) was conducted to examine the components outlined in the first phase of the Carbon Management (CM) framework. Concurrently, the research and development study (discussed further in Section 6.4) was initiated to validate the second phase of the framework. Unfortunately, time constraints precluded the evaluation of the framework's third and final phase. A crucial aspect of the testing was ensuring that the framework was user-friendly and could be effectively operated by the research partner's staff, mirroring the intended end-users from medium-sized businesses who may need more specialist support at their disposal.

3.3 Rationale for Mixed Methods Research: A Pragmatic Approach

The research questions proposed by the researcher suggested that a pragmatic approach was required to tackle the problem identified effectively. Pragmatism, a philosophical paradigm, is the principle of achieving results through action, of experience over fixed principles, meaning that ideas, policies, and concepts are seen as tools and instruments to be used in a practical application(Thayer and B.Rosenthal, 1999). The pragmatism paradigm thus suggests an amalgamation of purposes and procedures, where both must be considered holistically (Morgan, 2014a). Simply put, *pragmatism* may be defined as problem-solving in the most practical way, relative to specific conditions or situations, instead of on fixed ideas or theories (Cambridge Dictionary, no date; Merriam-Webster, no date).

A mixed methods research (MMR) approach has been used throughout this thesis. MMR carefully combines both qualitative and quantitative methods of data collection, analysis, and interpretation of obtained information. It adopts the prospective advantages of qualitative and quantitative research paradigms to achieve more diverse evaluations and enhance relationships resulting from more complex research questions (Shorten and Smith, 2017).

A vital attribute of the mixed methods approach is the efficient integration of qualitative and quantitative data; this requires careful 'mixing' of the two paradigms and is essential to preserving the method's robustness (Halcomb and Hickman, 2015). Previous research has suggested and argued that pragmatism as a paradigm provides the philosophical and methodological foundations when undertaking MMR (Charles Teddlie and Tashakkori, 2009; Biesta, 2010; Creswell, 2010). The approach can be looked at similarly to the pragmatism paradigm, acknowledging the value of qualitative and quantitative research methods to achieve a sensible solution to a complex problem (Feilzer, 2010).

'Designing and Conducting Mixed Methods Research', a book by Creswell and Plano Clark, provides theoretical foundations and practical guides on MMR and details the different research methods and designs found within the mixed methods approach (Creswell and Plano Clark, 2017). In a review of the book by Lee, the author details the target reader for Creswell and Plano Clark's book, stating that the content is aimed toward multidisciplinary researchers in architecture, environment, behaviour, and health (Lee, 2019). Architectural and environmental projects regularly deal with the complex interaction between buildings and their

users, with quantitative methods more commonly used to analyse buildings and qualitative methods used more frequently when dealing with user behaviour (Lee, 2019). This interaction suggests a more holistic, pragmatic approach to architectural and environmental research, as seen in the research undertaken as part of this thesis. In order to research, collect the necessary data, and pragmatically apply the findings, the research design framework (discussed in section 3.2.3 and shown in Figure 3-2) was most suited to a mixed methods design.

3.3.1 Applying Action Research to a Case Study

Case studies are not explicitly a methodological design; they provide the researcher with a specific case to be studied in-depth(Stake, 2005). Whether qualitative or quantitative methods are used, the case study provides the researcher with a real-world situation that offers a natural setting where data can be pragmatically collected, using whichever method is best suited to get the job done. This type of research is generally defined as applied research, specifically, action research, a sub-type of applied research.

Action research is 'the systematic collection of information' to make a positive social change (Smith, 1996). Kurt Lewin is generally known as the person who coined the term' action research' and described the term as 'research leading to social action'; Lewin also stated, 'research that produces nothing, but books will not suffice' (Lewin, 1948). In the 'SAGE Handbook of Action Research', Part One states that action research nearly always starts with a question similar to, 'How can we improve this situation?' (Bell *et al.*, 2008) , this question almost certainly inspired the work in this thesis and motivated the researcher to find an answer to the research problem.

The process of action research tends to include the following steps. Firstly, the research question/s are identified, and data is collected to provide a more detailed diagnosis. Following this, several possible solutions may be identified and researched, from which a plan of action is developed and implemented. Data emerges after initial implementation. This data is collected, analysed, and interpreted regarding the actions' success. Subsequently, the consequences of these actions are studied in an evaluation of the overall problem. Finally, general findings are identified, and the researcher must learn from the process as the procedure starts again until the questions are fully answered (O’Brien, 1998).

“Mixed methodology is characteristically used in applied research, thus inheriting the complexity of real-world challenges” - (Lee, 2019)

3.3.2 Strengths & Limitations of MMR

Creating a framework tailored for small and medium-sized enterprises (SMEs) necessitates a detailed and adaptable methodology for various business models. To develop such a framework, a specific entity, representative of the broader SME context, was essential to serve as an archetype for the framework's applicability. The chosen archetype required a partnership with a UK-based SME that could act as a testbed reflecting the broader SME environment, facilitating the framework's future applicability to a broader spectrum of SMEs.

The collaboration with Knowsley Safari, as detailed in Section 3.2.1, provided an ideal archetype for a longitudinal case study and was selected as the primary source of empirical data. Engaging in a longitudinal case study positioned the researcher in a unique environment that allowed for a natural development of ideas and solutions to tackle pragmatic, real-world issues faced by SMEs. Although case studies are conventionally qualitative, integrating quantitative data collection and analysis was deemed essential to enhance the generalisability of the findings. This mixed-methods strategy synergises the rich, detailed insights derived from qualitative research with the empirical precision of quantitative analysis, thereby establishing a solid basis for constructing an SME-centric framework.

One of the fundamental reasons for using a mixed methods approach is to combine the strengths of qualitative and quantitative methods. Firstly, it is important to identify what qualitative and quantitative research means and how the two methods have been used throughout this research.

Qualitative research is predominantly exploratory and explores new theories and hypotheses often established through case studies (Yin, 1989; Stake, 1995). During such case studies, an in-depth investigation into a person, group, event, or organisation is undertaken, whereby typical methods are used to collect data, such as interviews, focus groups, and participant observation (Morgan, 2014b). As a result, qualitative research tends to be more specific to individual cases. The overarching scope for the research was case based, with focus groups and informal interviews as the primary method used for qualitative data collection (detailed in section 4.3)

In contrast, quantitative research uses explanatory research methods that enable researchers to quantify their findings through numerical and statistical analysis. Results and findings are typically expressed as numbers, graphs, and tables (Slevitch, 2011). Statistical analysis provides a powerful tool in quantitative research to generalise results from a larger sample population (Arghode, 2012). Despite the case-based approach, the research questions proposed (outlined initially in Chapter 2, Section 2.9) suggested a more generalised method of analysis to improve applicability to other, similar cases.

A wide range of methods can be applied to research for both qualitative and quantitative data collection, analysis, and interpretation of information. When deciding which methods to use for the research, it was essential to identify the strengths and limitations of each method considered. Firstly, the potential methods applicable to the research were chosen. A comparison outlining their strengths and limitations was conducted, as seen in Table 3-1 (adapted from (Queirós, Faria and Almeida, 2017)).

Table 3-1. Comparison of qualitative and quantitative research methods

Method	**Type**[1]	**Strengths**	**Limitations**
Observation	QUAL & QUAN	*- Collect data concurrently with event occurrence* *- Discreet data collection does not rely on participants response* *- Flexible and adaptable methodology*	*- Time consuming* *- Impartiality of research required* *- Issues with real time data collection* *- Requires significant preparation*
Focus Groups/ Meetings	QUAL	*- Offer opportunity for in-depth discussion* *- Can prove vital if dealing with a business where multiple roles are involved* *- Lower costs and time in comparison to individual interviews*	*- Hard to control and manage* *- Difficult to organise and get the participation of people* *- Hard to analyse with conflicting views*

---

[1] Method typically used in traditional research approach of either qualitative or quantitative; QUAL = Qualitative; QUAN = Quantitative

Case Studies	QUAL & QUAN	*- Detailed information about individuals or an organisation can be obtained* *- Synergetic with focus groups* *- Offers good opportunity for innovation* *- Combines well with action research approach*	*- Can be difficult to generalise results if not chosen carefully* *- Possible ethical issues, particularly confidentiality if working with businesses* *- Difficult to create a case study that suits all subjects* *- Hard to identify cause-effect relationships*
Field Studies	QUAN	*- Natural setting allows more natural observations* *- Real world data* *- Larger scale projects*	*- Difficult to control variables* *- Occasional ethical issues* *- Difficult to reproduce exact conditions*
Simulation	QUAN	*- Complex systems can be studied* *- Ability to provide statistical analysis i.e. sensitivity of input variables or probability of results* *- Allows a reduced time frame of analysis enabling the researcher to establish conclusions more quickly* *- "What-if" analysis*	*- Building models required for simulation requires in-depth knowledge of the field* *- Time consuming and costly* *- Can require specific hardware or software tools to compute results*
Surveys	QUAN	*- Low-cost and quick to develop* *- Methodical data collection allows for more simple analysis* *- Increased range of participants* *- No influence from researcher*	*- Results can vary massively if survey is not structured clearly* *- Data can prove unreliable depending on quality of responses* *- Lack of emotion and behavioural changes in participants*

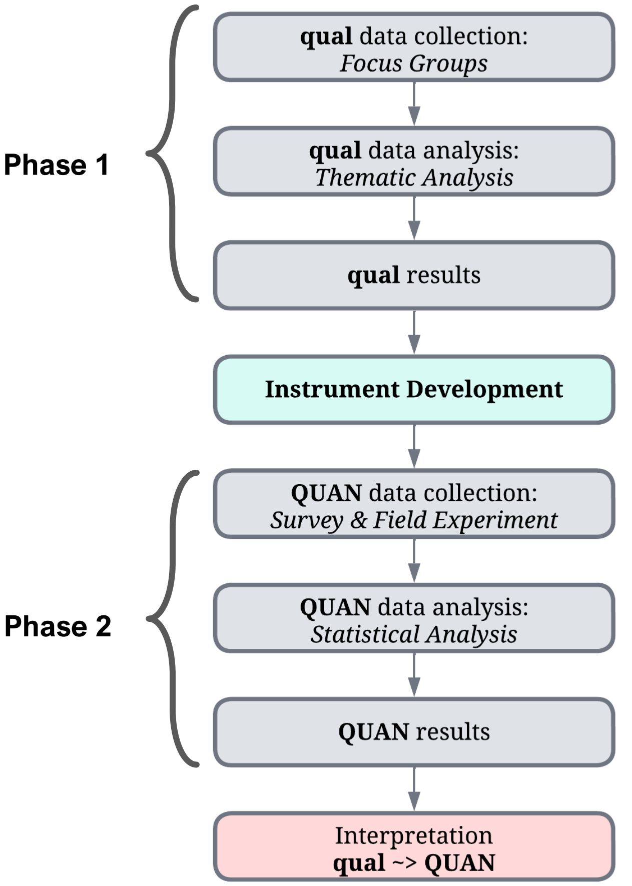
Table 3-1 presents the strengths and limitations of the available methods that would help answer the research questions. Despite case studies being classified as qualitative in Table 3-1, it is also seen that they are widely used in MMR and can be predominantly quantitative studies with qualitative data techniques being introduced to improve integrity (Mills, Durepos and Wiebe, 2010). The researcher decided that the case study approach would be most suitable with site surveys and field studies as the primary methods for data collection and framework testing, respectively. Focus groups and meetings were initially held to provide preliminary opinions of the research questions and helped during the framework development phase.

The case study involved designing a field study (discussed in Chapter 6) to thoroughly test for functionality, compatibility, and usability of the proposed framework (refer to Chapter 5).

3.4 The Exploratory Sequential Design: Instrument Development Model

Undertaking effective mixed methods research (MMR) requires systematic and careful integration of the two conventional research paradigms (qualitative and quantitative). This barrier required choosing the most appropriate design, with numerous studies comparing the different types of MMR and researchers attempting to condense the various types of designs into more general design approaches (Greene, Caracelli and Graham, 1989; Creswell and Plano Clark, 2007a; Clark *et al.*, 2008a; C Teddlie and Tashakkori, 2009; Schoonenboom and Johnson, 2017).

Creswell and Plano Clark (2007) condensed the numerous designs into four major types: Triangulation, Embedded, Explanatory Sequential, and Exploratory Sequential. Each primary design type consists of variants or sub-types used to explain the design procedure further. The design chosen for this study was the ***Exploratory Sequential Design: Instrument Development Model***, shown in Figure 3-3. This design was selected as the most appropriate due to its key focus on instrument development (further justifications in subsequent text). The process involved a two-phase approach, as Figure 3-3 illustrates.



QUAN *= Quantitative ;* ***qual*** *= Qualitative*

Figure 3-3. Exploratory Sequential Design: Instrument Development Model - Adapted from Creswell and Plano Clark (2007a)

3.4.1 Phase 1 – Exploratory Qualitative Research

The design process commences with collecting qualitative data as the initial source of information, which is subsequently analysed to explore the research topic and identify pivotal themes (Creswell and Plano Clark, 2007a).

3.4.2 Instrument Development

These qualitative insights inform the development of instruments, which, in the case of this thesis, is a framework, as outlined in Section 3.2.3 and discussed in more detail throughout Chapter 5.

3.4.3 Phase 2 – Quantitative Testing

The quantitative phase follows instrument development and was used to validate the newly developed framework. The process outlined in the framework was then analysed to test the reliability and validity and to refine it further if necessary.

3.4.4 Adapting A Two-Phase Design for Carbon Management Research

This research methodology, adapted from Creswell and Plano Clark (2007), aligns closely with the research objectives by offering a clear, structured approach. This approach, simpler in execution than models like triangulation or embedded designs, is flexible for single and multi-phase studies (Creswell and Plano Clark, 2007a; Clark *et al.*, 2008b). For this study, choosing this approach was crucial in influencing the development of a carbon management (CM) framework.

The initial qualitative phase (discussed further in Chapter 4) was critical in exploring the challenges and needs of SMEs, providing rich, detailed data to support the development of the framework (delineated in Chapter 5). The subsequent quantitative phase tested and validated the framework in a real-world case study – the entire study methodology can be found in Chapter 6. This methodology ensures the relevance of the findings to the target audience and enhances their generalisability, a crucial aspect for future application in the field (Morgan, 2017). This approach, particularly the CM framework (see Chapter 5 for comprehensive framework design), shows potential for application across various SME sectors beyond the case study at Knowsley Safari.

3.4.5 Identifying Potential Issues

Despite the appropriateness of the Mixed Methods Research (MMR) design for this study, the researcher proactively identified and catalogued several specific data collection challenges unique to MMR, as detailed in Table 3-2

Table 3-2. Potential Issues of Data Collection for Mixed-Methods Research

Potential Issue	**Description**	**Solution Proposed**
Integrating Multiple Data Types	*MMR is challenging to integrate qualitative and quantitative data effectively.*	*Use a theoretical framework supporting qualitative and quantitative data – Exploratory Sequential Design was chosen (see* Figure 3-3*).* *Develop a clear plan for how the two data types will complement each other (see* Figure 3-2*).*
Time and Resource Constraints	*MMR is more time-consuming and resource-intensive, given two types of data to collect, manage, and analyse.*	*Prepare and plan a data collection roadmap (see* Figure 3-4*).* *Identify data sources early and use software to support data analysis.*
Methodological Consistency	*Ensuring methodological consistency and coherence when integrating different methodologies can be challenging.*	*Create a research design framework that aligns with the research questions and objectives (see* Figure 3-2*)*
Data Analysis and Interpretation	*Multiple analysis methods can prove challenging, requiring skills in both forms of analysis.*	*Prepare and research various analysis methods and ensure the researcher is comfortable with both phases.*
Ethical Considerations	*Obtaining ethical approval through the University prior to any study can delay progress.*	*Apply for ethical approval for both phases as early as possible and plan for any potential delays.*

Given the limited timeframe for the research, the two-phase approach demanded meticulous planning to maintain the study's schedule. The data collection procedure needed to be outlined early in the study due to the complexity of collecting both qualitative and quantitative data. Section 3.2 outlines the research design and briefly mentions the data collection methods.

Figure 3-4 outlines the data collection roadmap used during the research; it started with a preliminary focus group to gather initial thoughts, ideas, and themes (see Chapter 4 for more information). Framework development occurred once all themes were identified (refer to Chapter 5). First, a site audit was conducted to collect data on buildings, lighting, heating & cooling systems, equipment & machinery, vehicles, and typical energy demands (refer to Section 6.3.2). Second, measured energy data was collected through a combination of energy bills and sub-meters – details of which can be found in Section 6.3.3.

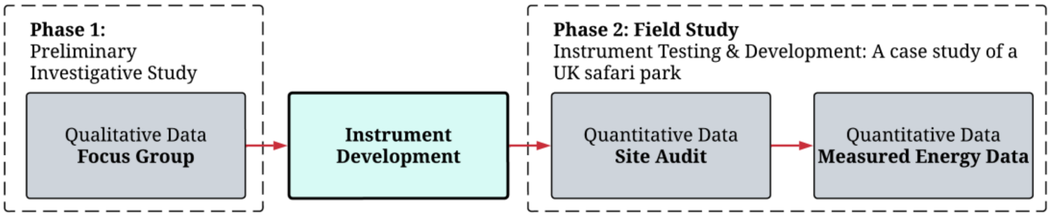


Figure 3-4. Data Collection Roadmap

3.5 Aligning Research Objectives with the Study Design

This research aims to develop a novel framework for implementing carbon management practices in medium-sized UK organisations. This section is designed to guide the reader through how each established objective aligns with specific parts of the study. It offers a clear roadmap, indicating where each objective is addressed and attempted to be fulfilled within the research.

3.5.1 Objective 1

> ***To comprehensively review current literature and identify knowledge gaps.***

The first objective, which involved understanding existing carbon management methodologies and identifying knowledge gaps, was tackled in the literature review presented in Chapter 2. The literature review consisted of two parts: a narrative and systematic approach was utilised to explore current practices and pinpoint areas needing more in-depth research. This exploration informed the research questions and laid the groundwork for the research design elaborated in this chapter.

3.5.2 Objective 2

> ***Utilise qualitative methods to obtain in-depth insights from industry experts about the challenges and drivers for SMEs in carbon management.***

Objective two focused on gaining rich and complex insights into business operations through a qualitative approach. The primary method employed was a focus group, detailed in Chapter 4, chosen for its ability to yield an in-depth understanding of the challenges and demands of a UK SME. Additionally, a series of unrecorded, informal conversations complemented this approach, enriching the researcher's learning. However, this thesis does not discuss these conversations due to their informal nature. The focus group study, with its academic rigour, was pivotal in supporting the development of the carbon management framework.

3.5.3 Objective 3

> ***Ensure the research methodology is pragmatic, particularly through collaboration with industry partners.***

This objective was accomplished via an extensive longitudinal case study with Knowsley Safari, the research sponsor and industrial partner, as detailed in Section 3.2.1. This case study immersed the researcher in a real-world setting, enabling a practical, applied approach to addressing SMEs' challenges.

3.5.4 Objective 4

> ***Develop a systematic process for SMEs to implement carbon management practices.***

To address this objective, Chapter 5 introduces a novel framework for medium-sized businesses to implement carbon management practices effectively. This framework represents a structured approach tailored to SMEs' unique needs and capabilities.

3.5.5 Objective 5

> ***Apply the findings and outputs of the research to a practical, real-world case study.***

The practical application of the research is demonstrated in a case study with Knowsley Safari, detailed in Chapter 6. The newly developed framework is subjected to a case study within this real-world setting. This study tests and validates the framework, showcasing its practicability and effectiveness in an operational environment.

3.6 Ethical Consideration

Adhering to ethical norms in research is crucial for several reasons; Resnik (2011) outlines these reasons in a paper on the importance of research ethics and are outlined below:

- Firstly, ethical norms support research goals like knowledge acquisition, truth, and error avoidance.
- Secondly, ethical standards foster collaboration values essential in multidisciplinary research, such as trust, accountability, mutual respect, and fairness.
- Thirdly, ethical norms ensure public accountability for researchers, particularly those funded by public money or research grants.
- Fourthly, these norms build public trust and support for research, as people are more likely to back projects they believe are conducted with integrity and quality.
- Lastly, research ethics promote broader moral and social values, including social responsibility, human rights, animal welfare, legal compliance, and safety.

These principles are integral to maintaining the credibility and societal impact of research (Resnik, 2011). Based on the proposed research design set out in Figure 3-2, it was identified that ethical approval would be required to undertake the focus group study, delineated in Chapter 4. In conducting focus group research, ethical considerations are vital to ensure participants' protection and the study's integrity. The following outlines the fundamental ethical principles and practices adhered to in this thesis:

1. **Informed Consent:** Prior to participation, all focus group members were provided with a detailed information sheet explaining the purpose of the study, the nature of the questions, and the intended use of the data collected. Participants were asked to sign a consent form acknowledging their voluntary participation and understanding of the study's aims and procedures. The Participant Information Sheet and Consent Form are in Appendix B1 and B2, respectively.

2. **Confidentiality and Anonymity:** To protect participant privacy, all discussions within the focus groups were treated as confidential. Participants were informed that their identities would remain anonymous in any reports or publications resulting from the study. Identifying information was omitted from all transcripts and notes.
3. **Data Security:** All data collected from the focus groups, including audio recordings, transcripts, and notes, were securely stored. Access to this data was restricted to the research team, and all electronic data were protected with password encryption as per the University of Liverpool's data storage policy.
4. **Ethical Approval:** This study received approval from the appropriate ethical review board, ensuring adherence to ethical standards and guidelines for research involving individuals. Ethics approval can be found in Appendix B3.
5. **Reporting of Findings:** In presenting the research findings, care was taken to ensure that the data were reported accurately and responsibly without misrepresenting the participants' views or experiences. More information can be found in Section 4.4 of this thesis.

3.7 Chapter Summary

This chapter presented the research methodology, diverging from traditional structures due to adopting a mixed-methods approach. It justifies the methods chosen for two primary studies, focusing on developing a novel carbon management framework for UK SMEs. Furthermore, it serves as the foundation for understanding the philosophical approach that underpins the rest of this thesis.

Section 3.2 outlined the overarching research design, incorporating qualitative and quantitative methods to understand the research problem comprehensively. The research, sponsored by Knowsley Safari, provided a practical, real-world case study essential for the research's applied nature.

Theoretical Framework: The methodology draws upon John Dewey's Five-Step Model of Inquiry, emphasising a pragmatic, empirical approach to learning and problem-solving. This philosophy significantly influences the research methodology, focusing on practical application and action research.

Section 3.3 delved into the rationale behind choosing a mixed methods research approach, emphasising pragmatism and the suitability of this approach for addressing complex, real-world problems.

Section 3.4 addressed the chosen research design, where the researcher utilised the Exploratory Sequential Design: Instrument Development Model, facilitating a two-phase approach to research, starting with exploratory qualitative research followed by quantitative testing.

The final part of the chapter, Section 3.6, addressed the ethical principles adhered to in the research, particularly in conducting focus group studies, to maintain credibility and integrity.

CHAPTER FOUR

4. Preliminary Investigative Study

4.1 Chapter Overview

Chapter 4 delves into 'Phase 1' of the research: a qualitative focus group study exploring SMEs' challenges in implementing carbon management (CM) practices and enhancing energy efficiency (EE). Following the research design framework (see Figure 3-2 in Section 3.2.3), this phase was pivotal in gaining insights to aid the framework development, as set out in Chapter 5. The chapter discusses the following:

Section 4.2 explains why this research is necessary and expands on its relevance to SMEs in the context of a low-carbon world.

Section 4.3 details the study methodology and design, including information on the study participants, the key themes and interview schedule, data collection procedures, and analysis techniques.

Section 4.4 delineates the ethical approval process to discuss how ethical issues were addressed, including participant recruitment and the process of obtaining university approval.

Section 4.5 presents the findings from the focus group study, highlighting the themes identified in the literature, followed by the six stages of thematic analysis (as discussed in Section 4.3.4).

Section 4.6 interprets the findings, providing insights into how carbon management and energy efficiency are perceived in the industry, especially by smaller companies.

Section 4.7 acknowledges the study's limitations and suggests potential enhancements for future research.

Section 4.8 concludes the chapter with a summary of the study's outcomes, highlighting its contributions to the research objectives.

4.2 Study Context

In Chapter 2, the literature review identified a notable gap in research on carbon management (CM) practices specifically tailored for SMEs (Hendrichs and Busch, 2012c; Conway, 2015b). This shortfall gained significance against the backdrop of the UK government's 2019 commitment to achieving net-zero carbon emissions by 2050 (Evans, 2019; Priestley, Hirst, and Bolton, 2019). While existing policies, such as the UK Emissions Trading Scheme (UK ETS)[1], and reporting frameworks like Streamlined Energy and Carbon Reporting (SECR) and the Taskforce on Climate-related Financial Disclosures (TCFD), have primarily targeted energy-intensive industries, power generation, aviation, and large corporations, the role of SMEs in national emissions, which contribute between 29-36% of the UK's total emissions (British Business Bank, 2021), has been relatively overlooked. his oversight, particularly the lack of qualitative research exploring the carbon impact and specific challenges of SMEs, motivated the focus group study in this thesis, aiming to deliver on the following research objective:

Utilise qualitative methods to obtain in-depth insights from industry experts about the challenges and drivers for SMEs in carbon management.

The research questions (RQs) established in Chapter 2 are revisited here to contextualise the study further. They were integral in shaping the study design, ensuring the focus group's alignment with the literature findings. The RQs are:

RQ 1. How do SMEs perceive carbon management practices within their business, and what is the extent of individual employees' knowledge in this field?

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[1] *The UK Emissions Trading Scheme (UK ETS) is a major climate change policy of the United Kingdom, established to reduce greenhouse gas emissions and replace the UK's participation in the EU ETS post-Brexit* (Borghesi and Flori, 2019)*. Operating on a cap-and-trade principle, it sets a decreasing limit on emissions from energy-intensive industries, the power generation sector, and aviation. Companies under this scheme receive or buy emission allowances, which can be traded and must cover their annual emissions. The system is designed to incentivize reductions in emissions, aligning with the UK's goal of achieving net-zero greenhouse gas emissions by 2050. The UK ETS is adaptable and may link with other global carbon markets* (BEIS and DESNZ, 2023).

RQ 2. **Can a generalised framework support UK-based SMEs in reducing their operational carbon impact, adapting techniques currently found at global, national, and corporate levels?**

RQ 3. **Can a UK-based SME achieve net-zero operational emissions at net-zero cost?**

RQ 4. **Would the practice of carbon management in SMEs provide a great enough impact on national emissions to necessitate action from the UK Government?**

The research design (outlined in Chapter 3) followed philosopher John Dewey's Five-Step Model of Inquiry and his pragmatic approach to problem-solving to answer all four research questions. The first step, identifying the problem, was accomplished in the literature review, leading to the formulating of the research questions. The focus group study, representing the second step, reflects on the nature of the problem by gathering existing beliefs and ideas. This qualitative method is ideal for efficiently collecting data and generating new ideas, allowing an in-depth exploration of industry opinions. The remaining steps in Dewey's framework, including proposing solutions and evaluating their effects, are covered in the subsequent chapters of the thesis.

4.3 Focus Group Methodology

The research's initial phase involved exploratory work, beginning with identifying key themes from the literature review. These themes, pivotal for guiding the study, were then explored in a focus group to gather opinions and extract information. This section details the methodology employed to accomplish this, starting with an explanation of the study design (Section 4.3.1), followed by the selection process for the study participants (Section 4.3.2), data collection procedure (Section 4.3.3), and finally the data analysis approach (Section 4.3.4).

4.3.1 Study Design

The primary purpose of the preliminary investigative study was to understand the level of awareness for CM (or similar sustainable practices) amongst typical business employees of small and medium-sized enterprises (SMEs). With that considered, a study question was developed to guide the research,

How do SMEs perceive energy and carbon management practices, and what is employee knowledge in energy, carbon, and sustainability?

A study design was developed to effectively answer this question, shown in Figure 4-1. The study design consisted of six consecutive steps required before the study could establish a comprehensive strategy.

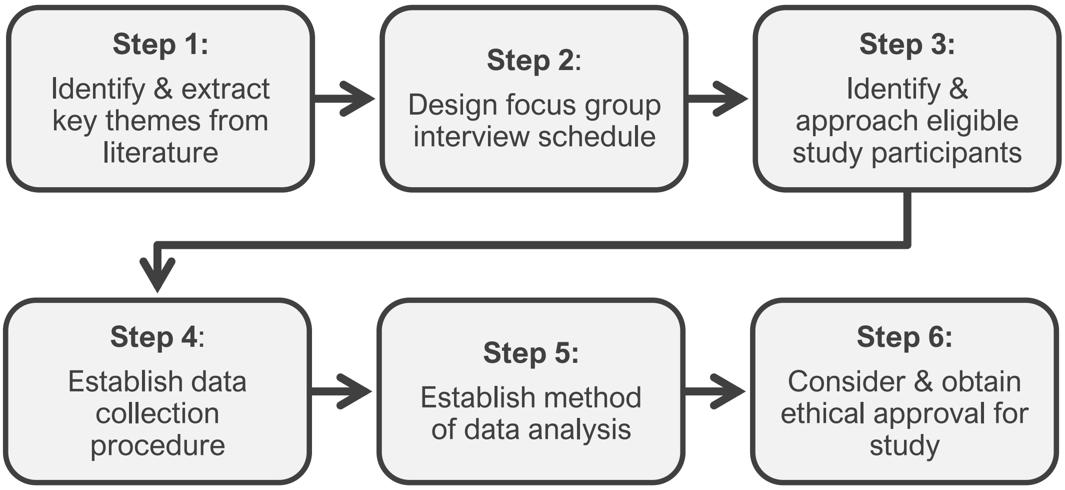

Figure 4-1. The six steps of study design for investigative focus group study

The initial step involved extracting key themes from the literature review to inform the focus group discussion topics and ensure the relevance of questions to the participants. This approach was crucial to align the focus group outcomes with the broader research objectives.

Following theme identification, the following steps included:

- developing a set of focus group questions,
- recruiting and informing eligible participants about the study's purpose and
- selecting suitable data collection and analysis methods for a typical focus group setting.

A critical component of the study design was obtaining ethical approval from the university to adhere to established ethical standards (detailed in Section 4.4).

While effective for initial data gathering, this focus group study was not intended to be exhaustive. Its primary role was gathering relevant information to support a more comprehensive subsequent study. The limitations of this approach and potential improvements are further discussed in Section 4.7.

4.3.2 Selection Process for Focus Group Participants

Whilst selecting the participants of the focus group, it was required to find a homogeneous yet varied group; this meant identifying participants with specific attributes. For this, an inclusion criterion was developed (shown in Table 4-1). Potential participants were found through several sources, including personal contacts, professional networks, and the research project industrial partner and sponsoring company, Knowsley Safari.

In the end, all participants who accepted worked at the collaborating industry partner, a large family estate comprising four well-established businesses; a stately home used for weddings and corporate events; a zoological park; an estate consisting of a business park with office space, residential properties, and farmland; and a stud facility for breeding horses. Each business operates independently and is classified as an SME, allowing for a diverse spread of eligible participants.

The most appropriate participants were selected based on their attributes meeting the inclusion criteria and their position (or role) in the company. It was essential to select a varied group of employees based on their hierarchical level in the business; this ranged from top-level management to personnel roles. This variation aimed to eliminate bias from the study. Each participant was approached individually and sent a 'participant information sheet' containing all the information required before taking part; this included the purpose of the study, why they had been chosen, and the handling of data and anonymity.

Table 4-1. Focus Group: Inclusion Criterion (IC)

IC#	Description
IC1	Participants must be an employee of an SME based in the UK
IC2	Able to communicate orally in English
IC3	Aged >18 years
IC4	Able and willing to provide written informed consent

Potential participants were identified and checked for eligibility based on the inclusion criteria (see Table 4-1); employees were then selected based on their role. The focus group consisted of six employees from SMEs with varying roles within the company. Ten participants were invited; however, only six agreed to participate; this follows the recommended number stated in numerous academic papers of four to ten (Morgan, 1996; Krueger and Casey, 2000; Krueger and Leader, 2002; Breen, 2006). The six attendees operated in different areas, including finance, property, research, management, and consultancy, and had varying levels of expertise in energy and CM. The participants and their roles are listed in Table 4-2; each participant was assigned a code to maintain anonymity. The focus group took place on 27th March 2018 and lasted approximately 90 minutes. The study was recorded using a hand-held voice recorder, and the researcher took additional notes during the session; the data was then cleaned and transcribed, ready for analysis.

Table 4-2. Focus Group: Study Participants

Participant Code	Company Position
A	Managing Director
B	Financial Controller
C	Research and Conservation Officer
D	Property Manager
E	Site Manager
F	Energy Consultant (External)

4.3.3 Data Collection Procedure – Identifying Key Themes

To inform the focus group discussion, key themes were extracted from the literature, aligning with the main research questions and the specific study question. These themes encompassed a variety of topics, including behavioural, technical, and management aspects of carbon management. The development of the interview schedule was guided by Krueger's (1998) methodology, which categorises questions into five types: Opening, Introductory, Transition, Key, and Ending. Krueger emphasises simplicity in question formulation, a principle adhered to throughout development.

4.3.3.1 Interview Schedule

Table 4-3 illustrates the key themes identified and the corresponding questions designed to explore these topics. The focus group was conducted in a semi-structured format, allowing for the natural evolution of the discussion. While not every question listed in the schedule was asked, all identified themes were adequately covered in the conversation.

Table 4-3. Key Themes & Interview Schedule

Question Type	Themes	Specific questions
Opening	Icebreaker	What do you think has the greater carbon footprint… Building a brand new 2-bedroom house OR having a child?[2] (Berners-Lee, 2010)
Introductory	Environment Sustainability Climate Change	What is the first thing that comes to your mind when I mention sustainability? From your knowledge, what are the major causes of climate change?
Transitional	Energy Carbon Behaviour Management	What are your opinions on the transition toward renewable energy? What do you think are the best solutions to reducing carbon emissions? From your experience, do you think employees care about sustainable practices or environmental initiatives in the workplace? What portion of allocated budget, if any, is used for sustainability and environmental projects?
Key	Energy Carbon Business	How seriously do you think businesses consider energy use? In your role, how much are you made aware of the energy used at your place of work? Do you know the carbon impact of business-as-usual operations at your place of work?
Transitional	SMEs	What are the typical drivers SMEs consider when embarking on new ventures?
Ending	SMEs Instruments, tools, and software Limitations	Are you aware of any available resources (such as documents, frameworks, or software) that help companies manage their energy use and carbon emissions? Do you think SMEs would directly benefit from understanding their carbon impact more? What do you feel would be the greatest barrier for SMEs when embarking on a carbon reduction project?

4.3.4 Thematic Analysis

Breen (2006) suggests that focus group data analysis should summarise key themes, notable quotes, and any unexpected findings. Morgan and Krueger (1997)

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[2] *For the interested reader, building a brand new 2-bedroom cottage equates to around 80 tonnes of CO2e, whereas having a child that lives a typical lifestyle in the UK with a life expectancy of 79 equates to around 373 tonnes of CO2e. – Data taken from* (Berners-Lee, 2010)

set out a list of analysis options, including listing/ranking, coding (key ideas, themes), content analysis, discourse analysis, and conversation analysis. Braun and Clarke (2006) highlight content analysis and thematic analysis as the most common methods for focus groups. This study chose thematic analysis for its straightforwardness and efficiency, which is particularly suitable for a preliminary investigative study. This method allows more time for the primary research and development of the framework (detailed in Chapter 5).

Braun and Clarke (2006) developed a six-phase process (see Table 4-4) for conducting thematic analysis initially designed for psychology research, however, it has since been adopted a proven method in a wide range of applications (Tate, Ellram and Kirchoff, 2010; Sandelowski and Leeman, 2012; Vaismoradi, Turunen and Bondas, 2013; Nowell *et al.*, 2017).

Table 4-4. Six-phase process of thematic analysis (Braun and Clarke, 2006)

Phase No.	Description	Reference Code
1	**Familiarising with Data:** Transcribing audio data and noting initial ideas.	(P1)
2	**Generating Initial Codes:** Assigning codes to specific data extracts, with some extracts receiving multiple codes.	(P2)
3	**Exploring Themes:** Identifying overarching themes by analysing relationships between codes and themes.	(P3)
4	**Reviewing Themes:** Refining themes through a two-stage review process, assessing coded data's coherence and the themes' validity.	(P4)
5	**Defining and Naming Themes:** Developing a thematic map and defining each theme for consistency and relevance.	(P5)
6	**Discussing Findings:** Compiling an analytic narrative to discuss the study's findings coherently and meaningfully.	(P6)

This process was diligently applied to the focus group data. The data was systematically coded, collated into themes and sub-themes, reviewed, refined, and analysed to construct a cohesive and insightful narrative. The final stage involved presenting the findings rationally and engagingly, answering the study question and contributing to the research. A detailed discussion of the study's findings is presented in Section 4.5.

4.4 Ethical Approval

Obtaining ethical approval for the focus group study required several steps to carefully consider potential participant selection and the approach to ensure ethical integrity. The study, a collaboration between the university and the industrial partner, Knowsley Safari, primarily targeted staff members from the partner company for participation. To address potential ethical concerns, such as conflicting views among employees, the focus group questions were meticulously designed to avoid sensitive issues.

The primary aim of the research was to explore and develop a novel carbon reduction methodology for SMEs, using the industrial partner's diverse business model as the overarching case study. Accordingly, participants from this company were deemed most suitable for the focus group. Ethical approval was then sought and granted by The University of Liverpool.

Participants were initially approached in person to gauge interest, ensuring a variety of job roles and expertise. Subsequently, an official email invitation was sent, including an information sheet (see Appendix B1) detailing the study's purpose, data handling procedures, including anonymisation, and withdrawal instructions. A consent form (see Appendix B2) was also provided for signing before the focus group commenced.

On the day of the focus group, participants were reminded of the data collection and handling process. To maintain anonymity, participants contributed under assigned codes as per Table 4-2, ensuring confidentiality throughout the research.

4.5 Study Findings

4.5.1 Identifying Themes from the Literature

The focus group loosely followed the predefined interview schedule, with some questions omitted as discussions evolved. Once a discussion had reached saturation, the researcher proceeded with a follow-up question to probe for further information on interesting topics that arose. Initial themes were deduced through an assessment of the literature, as conducted during Chapter 2, to enable potential ideas and concepts to be established prior to the data collection phase. Table 4-5 provides a summary of the initial themes inferred from the literature; this allowed for the development of thematic concepts to aid the construction of the focus group study design, including the formation of the interview schedule. In addition, this initial assessment highlighted the complexity of possible solutions surrounding the novelty of developing a framework to achieve net-zero carbon emissions in UK-based SMEs.

Table 4-5. Summary of initial themes identified in the literature

Theme	Thematic Concepts, Sub-themes & Keywords	Key References
Environment	Natural science, anthropogenic impact on the environment, greenhouse gas emissions, climate change, technology, energy, sustainability, environmental impact assessment.	(Burgess, 1837) (Fleming, 1999) (Crutzen and Stoermer, 2000) (Le Treut *et al.*, 2007)
Policy	United Nations, intergovernmental organisations, environment programmes, multidisciplinary, climate change, scientific climate research, global policy, national policy, Kyoto Protocol, Paris Agreement, COP meetings, UNFCCC, assessment reports, energy supply, business, transport, public sector, private sector, residential, agriculture, industrial sector.	(IPCC, 1990) (United Nations, 1992) (Le Treut *et al.*, 2007) (Falkner, 2016) (Dimitrov, 2016) (Stern, 2007) (BEIS (UK Gov), 2017)
Business	Climate policy, energy policy, legislations, regulations, public relations, targets, supply chains, relationships, competition, strategy, financial incentives, drivers, business categorisation, corporate, SMEs, low carbon economy, stakeholder involvement, disclosure.	(BEIS (UK Gov), 2017) (Doda *et al.*, 2015) (Revell, Stokes and Chen, 2010) (Conway, 2015d)
Management	Decision making, carbon management, energy management, water management, waste management, inventory management, strategic planning, masterplan, supply chain, communication, training and education, research and development, accounting and finance.	(Schaltegger and Csutora, 2012b) (British Standards Institution, 2018) (Graafland and Smid, 2016) (Cochran and Wood, 1984)

Energy	Renewable energy, low carbon energy, energy supply, transport, business, residential, agriculture, public sector, private sector, electricity generation, fracking, oil drilling, shipping, aviation, energy monitoring, technology, energy conservation measures, energy efficiency.	(Runci and Dooley, 2004) (Davis *et al.*, 2018) (Yan, 2015) (Goswami and Kreith, 2007)
Carbon	Greenhouse gas emissions, carbon dioxide, CO_2e, zero carbon, net zero carbon, low carbon, embodied carbon, operational carbon, carbon management, conversion factors, carbon footprint, carbon policies, carbon accounting, marginal abatement cost curves.	(Garg and Gillenwater, 2010) (Houghton and Dhakal, 2010) (Runci and Dooley, 2004) (Zhou, 2020b) (Doda *et al.*, 2015) (Berners-Lee, 2010)
Instruments, Tools, Protocols & Software	Climate models, GHG protocol, ISO standards, energy monitoring, methodology, technology, web development, mobile apps, availability, cost, decision making, automation, strategic processes, finance, limitations, scope and boundaries, research and innovation.	(WBCSD and WRI, 2004) (ISO, 2019a) (Lenzen, 2008) (Le Treut *et al.*, 2007)
Behaviour	Behavioural change, training and education, management techniques, stakeholders	(Salim *et al.*, 2018) (Williamson, Lynch-Wood and Ramsay, 2006)
Finance	Cost, marginal abatement cost curves, supply chain, financial incentives, economic growth, capital investment, CAPEX, operational expenditure, life-cycle assessment, stakeholders, shareholders, reporting and disclosure	(Kesicki and Ekins, 2012) (Finnegan, 2017a) (Carbon Trust, 2019a)

4.5.2 Data Familiarisation

As outlined in section 4.3.4, the thematic analysis followed Braun and Clarke's (2006) six-stage methodology. This began with data familiarisation (P1), where the focus group transcript was read multiple times for initial understanding and cleaning. Participant names were anonymised in line with ethical procedures.

The purpose of this phase (P1) was to focus on data familiarisation; therefore, no detailed analysis took place; however, the researcher did make some initial observations that would form the building blocks for phase two of the analysis. As the focus group was conducted with participants working at the same company, there were several discussions specific to company operations; these discussions were omitted from the transcript as they are irrelevant to this study. Initial observations showed that participants were more involved when discussing management decisions, energy, carbon, and finance, with increased contribution during these discussions. Further observation showed that issues surrounding management and business operations were clearly of importance to certain participants in managerial roles. Participants tended to contribute to the discussion based on their background and role within the business; for example, when discussing management issues, higher-ranking members seemed more engaged; likewise, during discussions on cost and finance, more significant contributions were made by those working in that area.

4.5.3 Generating Initial Codes

During phase two (P2) of analysis, the transcribed and cleansed data was coded to collate similar themes and ideas that emerged from the data. The entire transcript was coded, and no data extracts were excluded. Certain extracts were placed in a miscellaneous code when the focus group participants went off topic to discuss matters unrelated to the focus group questions asked; these have not been included in this study as they do not present any relevant or valuable findings. A word cloud (illustrated in Figure 4-2) was computed using Nvivo 12 software to represent the most frequently used words and aided the coding process by highlighting potential themes.

Figure 4-2. Focus group word cloud

4.5.4 Exploring Themes

Stage three involved sorting these codes into potential themes and collating the relevant coded data extracts (quotations) within the identified themes. A thematic coding matrix (seen in Table 4-6) was used to highlight the total number of references identified for each code. In addition, quotations have been included to support the formulation of each code, each quotation has been tagged with the corresponding participant, and participants were tagged as per Table 4-2

Table 4-6. Thematic coding matrix

Theme	Total No. of Refs	Key supporting quotations
C1 Behaviour	4	"And we were conscious of the fact that we should be actually influencing behaviours and attitudes..." (Participant A) "You already made the point that in the future staff may leave, new staff will start." (Participant C) "How you nurture your staff to switch the light off every time you leave the room" (Participant D) "there's potential to get in early as well... there's a potential to be part of something early on and take advantage of that." (Participant D)
C2 Business Type	47	"Let's actually really get down to the basics, but also it was running in parallel with our needs to be more of an ethical, carbon conscious organisation as well, because we were conscious that we are in effect an eco-attraction." (Participant A) "M&S used to have a good model actually…" (Participant D) "No, it's certainly something we're doing on the wider estate, is actually looking at the yield on the capital assets separately, where the presumption is that agriculture is the one that delivers or the residential properties, but actually, they're not that we're still in that Victorian mindset pursuing that actually, fixed assets are the ones that deliver the returns, but they're not. And they're also very prone to politics and tax rates." (Participant A) "they want SMEs to come in and speak to them…" (Participant F) "In terms of why would be so attractive? Is it because of the size and the scale of our land?" (Participant B) "So, exploring the full range of available technology, and also looking at the costs, and how viable they are for a business of this size." (Participant F)
C3 Carbon	13	"In other words, that actually our carbon emissions were 19% down on 2017" (Participant A) "…so, we're reducing CO2 emissions in any developments that we do in the future" (Participant D) "For example, say If you do this over the next year, it's going to reduce CO2 emissions." (Participant D)

		"I mean, in terms of carbon neutrality there could be two simple things to do. You could offset all the carbon, which is a bit of a…" (Participant F) "Reducing carbon emissions should have the integral benefit of cost sustainability, as well as reducing emissions as well." (Participant A)
C4 Cost	55	"We went to another company and there was a board outside the restaurant, saying 'savings year on year'." (Participant B) "I'd love to put a cost against that as well." (Participant A) "It highlights a lot of the hidden costs as well. If we identify one item to generate 100 grand a year, but actually if 30 (thousand) is going on energy supply, whether it be heating, lighting, or whatever it is, it changes the viability." (Participant D) "(referring to sub-metering companies) there are companies you could engage with, we spoke about it last time, and they'd charge you 50 to 100,000 (pounds) and they'd monitor every single bit of kit, but then that's a spend" (Participant F) "We've had so many quotes before, we've been down this path many times, I never found one… I think the cheapest one was the guys who fitted need the water meters, the alarms on the water meters. But even that was a few thousand pounds, and we weren't convinced we're going to see a huge return on it." (Participant E) "it does need to balance as well, whether we trying to be… What's the primary benefit to reduce money? Or is it to…" (Participant D) "I think it would be worth talking about cost at this stage, it'd be useful to get the input, but when we mention costs, we're talking about simple payback and net present value, ROI. The basic financial indicators of costs." (Participant F) "Yeah, I'd love to see a cost!" (Participant A) "you know, its hidden cost, isn't it? It's a hidden cost until it's allocated to that individual cost centre." (Participant D) "And I think that, and again, it's also that cost benefit analysis as well." (Participant A) "But if you take into account all the other aspects like payback period, and then we could have a list of quick wins, and we could have a list of things for capital investment, you know, going forward." (Participant D) "we're still in that Victorian mindset pursuing that actually, fixed assets are the ones that deliver the returns, but they're not." (Participant A)
C5 Culture	2	"And then the other bit is really the cultural bit, management… but is the management side of it, which is probably the wider cultural aspects isn't it but, how we can pump that out to the rest of staff and get everyone on board." (Participant D)

		"In an ideal world, it'd be good to be able to set a budget for energy consumption. And then be able to see how master planning, or facilities management, or cultural change and all those things that we employ, how they are reducing the actual cost in line with that." (Participant D)
C6 Data	18	"…it allows us then to start using the data as management tools, but also, that's the strategic side of it as well." (Participant A) "Yeah, we need a baseline, we need to know when it's going above, say typical consumption" (Participant E) "Do we feel that there's enough data in there to give a list of priorities to be able to say, what do you think needs doing? Or is it? Is it enough at this stage?" (Participant A) "At the moment, this is this kind of data being generated as long as someone is physically going around checking the meters, isn't it?" (Participant C) "…and of course, years' worth of data would be just invaluable to have so that we could see the trends." (Participant A) "Top Level dashboard sort of data" (Participant E) "I don't know how, 'real-time' the data is" (Participant A) "Well, that's the key thing is being able to monitor it and maintain the integrity of data." (Participant B)
C7 Energy	45	"that's why there was a push towards gas and now it's flipping back toward electricity." (Participant D) "Even last week, for example, I was talking to a company called Social Energy who utilise battery technology combined with solar energy..." (Participant F) "Biomass is now where they're trying to sell energy back, but it's like you say, trying to predict that..." (Participant D) "And I've always thought actually it'd quite good to have that portfolio of energy generation almost," (Participant A) "I mean, what we will do in an ideal world, we would be looking at things like design guide that takes into account embodied energy and materials where we source it from…" (Participant D) "Well, any feasibility I do for development will take into account energy consumption as part of it." (Participant D) "What they could also do is overproduce electricity or power, and sell it to the grid, because you've got land availability and things. And because of your status, and the size of your energy spend." (Participant F) "I think we're quite close to actually needing to form a strategy, that wider energy strategy..." (Participant A) "It's mainly just energy and water consumption for now." (Participant E)

C8 Financial Incentives	13	"... for example, the feed in tariff finishes next month, there's no more of that. But there could be another announcement for further little grants" (Participant F) "you could look at things like enhanced capital allowances, things that and the energy technologies list or the carbon trust. So, anything you buy from That list has an ECA attached to it, a tax reduction, things like that" (Participant F) "But in terms of all those grants, initiatives, you know, partnership arrangements, that's all critical stuff" (Participant D) "Why would the ESCOs want to engage with us?" (Participant B) "But RHI, things like that, they're going to stay for a bit." (Participant E)
C9 Infrastructure	19	"But these are things that we've just started doing now in terms of mapping infrastructure and the likes." (Participant D) "Yeah, so for example, insulation, and PIR sensors, the lighting, that seems doable?" (Participant A) "Because originally, we're looking at bringing gas in... we brought gas across the bypass, but we stopped at the wall here. Because obviously, that's there to plug into as we change the infrastructure, do further work." (Participant D) "it's almost as if we've got this palimpsest here, we've got this this dysfunctional infrastructure, and I always say we just need to hire a JCB or whatever, just bulldoze the whole lot and start again..." (Participant A) "Oh, yeah. I mean, that's ideal isn't it to just be able to log on to a dashboard and see, whatever it is... monitoring energy in a building etc..." (Participant E)
C10 Framework & Model	39	"User friendly" (Participant C) "Yeah, I agree... It should be intuitive" (Participant B) "I think that could be on some sort of dashboard, and I think that we suggest that we keep this dashboard going the whole time." (Participant A) "It's something that we should be able to tap into." (Participant C) "Could this be, for example if we were making a new development we put stuff information into it, and it gives us ideas?" (Participant C) "Fundamentally, you've got an alarm system in there and so for instance, you've got the forecast there. If we saw it went, it was above the forecast just in normal operation, then that's an alarm system. Which I think is great." (Participant A) "So, we can then tie that into the master plan" (Participant D)

		“if a framework could steer us in the right direction and… if you do this with this, this or this, this or that, we can then get the market cost for a solution, do an assessment, you know, and then bounce that off…” (Participant D) “I'd really like to explore how we can actually keep this going. Explore the longevity. Whether it becomes somebodies’ job, how do we future proof it… How can we extract data easily?… But we do need to use this also for communications and PR.” (Participant A) “Yeah, possibly a traffic light system or something of the likes…” (Participant E)
C11 Instruments, Tools, and Software	13	“We've just got the CAD drawings and plans together now we're just about to start doing all the schematics, and it needs investigation.” (Participant D) “They call it MACC analysis, marginal abatement cost curves. So, you see how the graph, which is an X and a Y, anything on the on the left-hand side and below the x axes, save your money per year as a cost reduction, so you can rank them all in one graph,” (Participant F) “Is there a plan or thought to put this onto an app, to transform this dashboard into an app?” (Participant E) “In fairness though, a majority of apps are made from Excel models” (Participant F)
C12 Management	39	“Yeah, there's no facilities management, like utilities management etc…” (Participant D) “And then the next bit is probably, which was outside and it's our people feed that out from all sorts of business to the visitors and guests.” (Participant D) “Because actually, what would be beneficial, when you split it down into say perhaps, zones, is to actually say that so for instance, say building 1 uses 10 percent of the energy, and this energy is actually lighting. So, for me, really, it's a management tool.” (Participant A) “it allows us then to start using the data as management tools, but also, that's the strategic side of it as well.” (Participant A) “But doing it in a way that has longevity, and grows with the master plan, and can be tested year on year” (Participant F) “If I had an aerial view of this site, profile for each building, energy consumption… you know, I will understand it from the type of construction and how much work required to bring it up to scratch, all those things influence the master plan.” (Participant D) “But from my perspective, you can imagine… energy accounts come out every month alongside GPs (gross profits) on food and beverage, and to just be able to say… well actually why have we used 45% more energy in the restaurant or whatever. So, it's almost bringing it into those KPIs (key

		performance indicators). And that's how you make it quite real.” (Participant A)
C13 Risk	3	“A lot of those opportunities mean that we don't have to put too much capital down in one lump sum. So, it reduces the risk, doesn't it? Yeah. So, if we could share the risk with third parties, I think it's good to see it all. And that's the thing...” (Participant D) “So, it's not ideal but then they're taking all the risk in a way” (Participant F) “But there's been lots of case studies, for example pretty much every hospital now has an ESCO involved with them. And it depends on your appetite and trusting working with a third-party company” (Participant F)
C14 Sustainability	7	“I mean, what we will do in an ideal world, we would be looking at things like design guide that takes into account embodied energy and materials where we source it from.” (Participant D) “Reducing carbon emissions should have the integral benefit of cost sustainability, as well as reducing emissions as well.” (Participant A) “And then things like embodied energy. So, going further away, what materials we're sourcing, where we're getting it locally, we've got a lot of timber that we can create on site as well.” (Participant D)
C15 Technology	28	“Even that, has been a major feat, because you've had to calibrate all the equipment” (Participant F) “a comprehensive analysis of all the potential opportunities, cost saving solutions, energy efficiency solutions, renewable technologies, alternative technologies.” (Participant E) “Yeah, that's what we work on the ROI for the green payback schedule. So, we’ve got a biomass boiler... we've got solar... hydro at the crag.” (Participant B) “In essence, you have to give control of all the technology.” (Participant F) “They use a variety of solutions, but solar seems to be preferable because it's quick and easy.” (Participant F) “it's like a roll of carpets, that's a solar panel So they roll out and it has an adhesive back, and they stick it onto a wall or stick onto a roof and connect it up, and there's your solar PV.” (Participant F)
C16 Thermal Performance	4	“…and then the other stage would be for us improving thermal performance of our existing assets.” (Participant D) “then whatever we do to the building, how we make it thermally perform, perform better, which we've got some good insights that we can standardise those things, you know.” (Participant D) “Is it actually to be able to measure the thermal performance? And then come to me and say, well actually it's going to cost 200,000 pounds, but actually, we're going to make a return.” (Participant A)

		“That's the challenge a little bit with some of the bigger capital elements, or bigger buildings. Because the age of them they need quite a lot of investments in terms of thermal performance.” (Participant D)
C17 Training & Education	9	“And I've always thought actually it'd quite good to have that portfolio of energy generation almost, because the cost benefit but also, the educational side of it as well.” (Participant A) “My first thought was staff. If you're thinking of what we going to use it for... should we use this or should we use this? Should we put it here? or should we put it there? And if the model is designed to help answer those questions, you don't want to be thinking, what do I do? How do I put this in?” (Participant C) “So, I think that that might be an overall headline to display to the public” (Participant B) “but, how we can pump that out to the rest of staff and get everyone on board.” (Participant D) “It's like anything, any strategic decisions that are made, we have to articulate that in layman's terms a lot of times.” (Participant D)
C18 Water Management	13	“I think the cheapest one was the guys who fitted need the water meters, the alarms on the water meters.” (Participant E) “It wasn't really giving us any information of any detail. We had to do the filtration every day we had...” (Participant E) “Yeah, for even irrigation. Rainwater harvesting would be great for irrigation of the plants and stuff like that...” (Participant D) “Our surface water drainage charge is just a thousand pounds shy of ‘X’” (Participant A)

Quotations in Table 4-6 have been used to help interpret the data. They provide the most relevant evidence for each meta-theme and sub-theme identified later in the analysis stage.

Initial themes identified in Phase Three of the analysis aligned with the themes identified in the literature, specifically in management, energy, carbon, and finance. A thematic map (Figure 4-3) was developed to identify relationships amongst the emerging themes and provided a conceptual vision for reviewing, condensing, and finalising key themes.

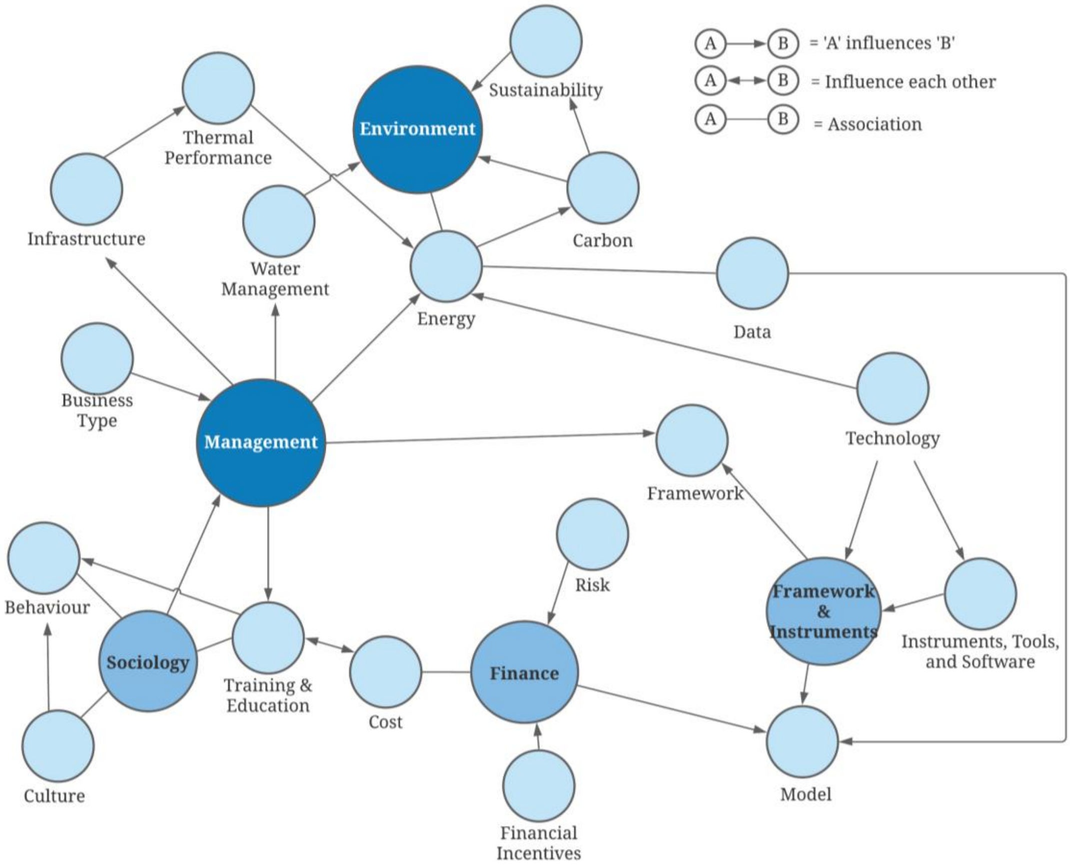

Figure 4-3. Thematic Map - V1, formulated during phase three (P3) of analysis

Further analysing the initial codes and developing relationships supported the emergence of candidate themes. During this phase (P3), it was evident that some of these were incomplete themes with a lack of supporting evidence; instead these early ideas would merge into more prominent themes and develop sub-themes. From the thematic map shown in Figure 4-3, emphasis has been placed on specific themes with more complex and detailed relationships. As a result, these themes stood out, giving the potential to develop into more robust, centralised topics. Figure 4-3 shows how 'Sociology', 'Environment', 'Framework and instruments', 'Finance', and 'Management' emerged as key themes, linking other themes to develop a cohesive relationship.

4.5.5 Reviewing Themes

Whilst Figure 4-3 expresses the candidate themes devised, phase four (P4) required refinement of those themes via a two-stage process. Phase four, stage one (P4.1) involved reviewing each coded data extract to establish whether or not they formed a coherent pattern within each theme. For example, under the theme

‘Financial Incentives,’ the following quotation supports a strong relationship between *data* and *management* to inform operational business decisions:

> *“it allows us then to start using the data as management tools, but also, that's the strategic side of it as well.” (Participant A)*

This relationship was not considered during phase three (P3) but clearly showed a strong correlation between the two themes. Another example shows how the two following quotations from the candidate theme, 'Behaviour', provide a noticeable trend in the discussion that supports the development of that theme:

> *“You already made the point that in the future staff may leave, new staff will start.” (Participant C)*
>
> *“How you nurture your staff to switch the light off every time you leave the room” (Participant D)*

Both quotations mention the behaviour of staff members within the workplace, this demonstrates the importance of these quotations within the theme 'Behaviour' and provides an exciting finding in the results. Whilst showing a clear pattern within the theme, questions could be asked on whether these quotations provide enough evidence to support this as a major theme. A similar analysis was completed for all candidate themes, identifying interesting findings and coherent patterns and removing any data extracts that did not fit within the scope of that topic.

The second stage of phase four analysis (P4.2) involved a similar process; instead, this time analysis took place in relation to the entire dataset. Uncertain themes were reviewed and merged into more established themes with stronger relationships in the dataset. This example shows how two candidate themes established in phase three (P3) merged to become one theme as data extracts overlapped. The following quotations were coded under both 'technology' and 'Instruments, tools, and software' as they seemed to demonstrate aspects of each theme:

> *“We've just got the CAD drawings and plans together now we're just about to start doing all the schematics, and it needs investigation.” (Participant D)*
>
> *“Is there a plan or thought to put this onto an app, to transform this dashboard into an app?” (Participant E)*

Rather than having two relatively weak but similar themes, they merged to become one more prominent theme under a new code, 'Technology & Software.' A further example of this merging (or data refining) was considered under the codes 'Behaviour,' 'Culture,' and 'Training & Education', as there were very few supporting quotations for each. Instead, data extracts were grouped to become a more comprehensive theme. A new thematic map was created to reflect these changes and refinements (shown in Figure 4-4). The new map helps to visualise the reviewing process and introduces new relationships within the dataset.

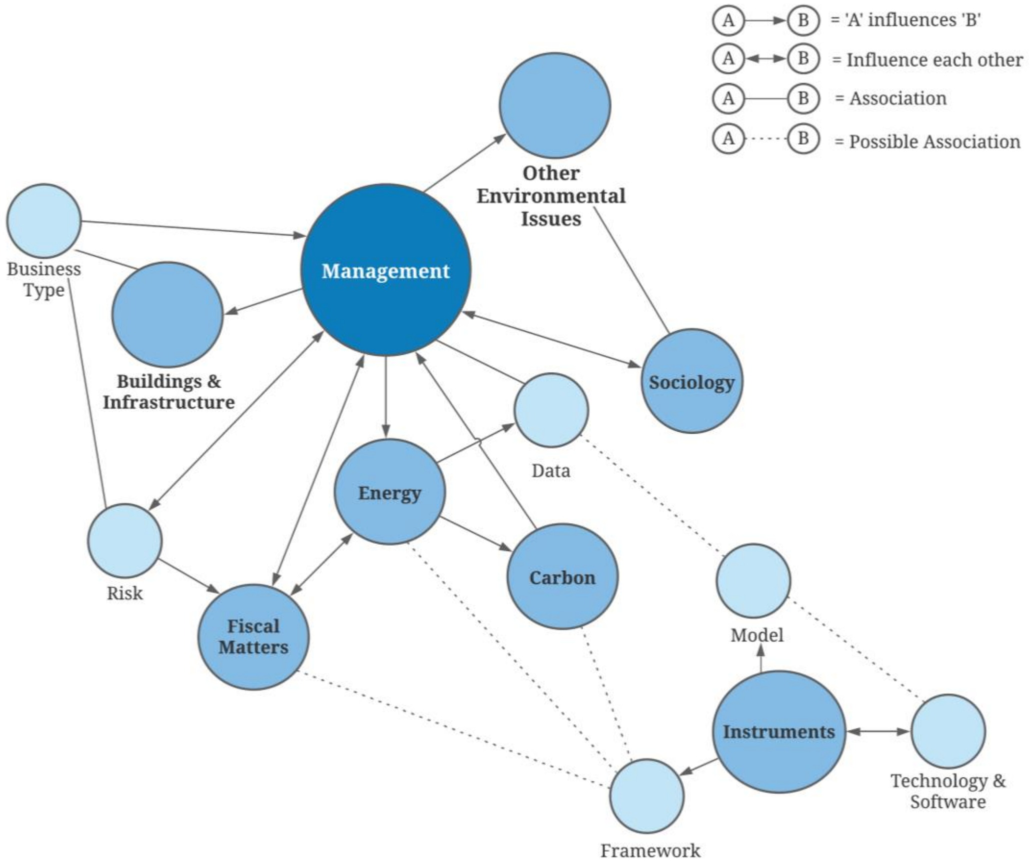

Figure 4-4. Thematic Map - V2, formulated during phase four (P4) of analysis

Comparing the first thematic map to the revised version (see Figure 4-3 and Figure 4-4 respectively), it can be seen that initial codes have been condensed into a more defined map with broader themes emerging. Management is the most significant theme with the most complex relationships in the dataset. The sheer prominence of management within the focus group altered the focus of the conversation in the subsequent interview questions. Both energy, carbon, and fiscal matters remained paramount to the conversation as the building blocks for most discussions. This prominence is likely driven by the interview questions and the topics initially set out. Sociology emerged to collate the data extracts relating to human behaviour, social relationships, culture, and education; this created a more complex theme, allowing for a detailed narrative to mature.

Phase five of analysis required a satisfactory thematic map of the data. Figure 4-4 represents a nearly complete thematic map; however, there were still some loose themes to address before moving on to the fifth and final analysis phase. Once again, data extracts were scrutinised to condense the dataset into more clear-cut themes; this could be used to tell a complete story of the data and help answer the study question set out in the study design (see section 4.3.1). A third and final, fully refined thematic map was developed (see Figure 4-5) that defined three meta-themes extrapolated from the dataset. The three meta-themes established were 'Energy Management', 'Strategic Management', and 'Data Management', which contained sub-themes and complex thematic relationships amongst the hierarchy.

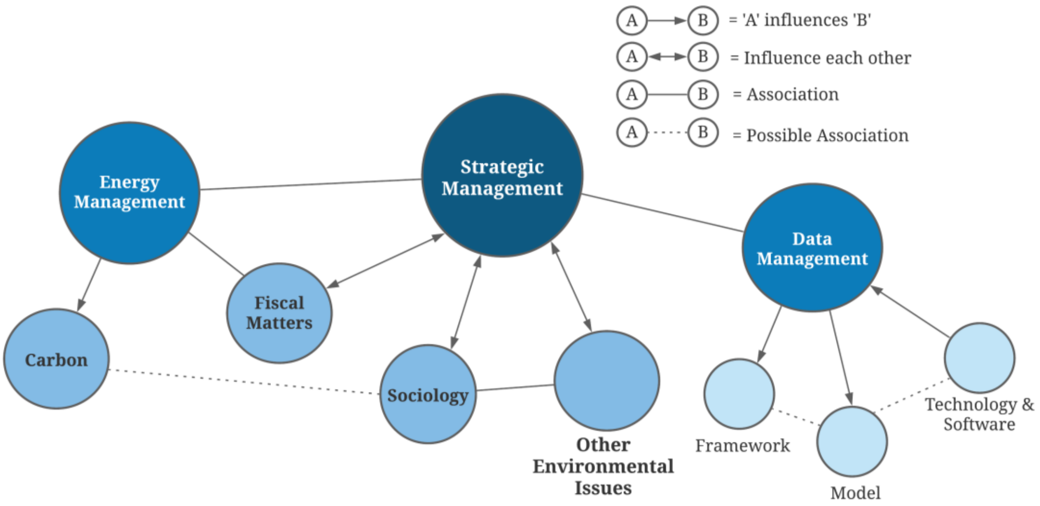

Figure 4-5. Thematic Map - V3, formulated during phase four (P4) of analysis

4.5.6 Defining and Naming Themes

Achieving the satisfactory thematic map set out in Figure 4-5 allowed for the final stage of analysis (P5). Phase five involved defining and refining the themes to be presented for analysis in the discussion section; this meant identifying the essence of the content, defining the ideas extracted, and deriving the overall findings to provide sufficient information that would assist in the development stage of the research (see Chapter 5). Table 4-7 outlines the meta-themes identified and the corresponding sub-themes, relationships, and thematic connections, which have also been included to outline the complexity of the data. The focus group presented an overview of the main themes to consider for the potential development of novel framework; it provided an outlook on how employees from the industry perceive issues relating to energy and CM and demonstrated the most important factors considered in a typical small business.

Table 4-7. Focus group thematic analysis

Meta-Themes	Sub-Themes	Relationships & Theme Connections
Strategic Management	Fiscal Matters	▪ Energy ▪ Risk ▪ Framework concepts ▪ Instrument concepts ▪ Technology, software, and methodology
	Sociology	▪ Behaviour ▪ Culture ▪ Training and education ▪ Energy generation ▪ Carbon emissions ▪ Other environmental issues ▪ Framework concepts
	Other environmental issues	▪ Sociology ▪ Fiscal matters ▪ Framework concepts ▪ Technology, software, and methodology
Energy Management	Energy	▪ Carbon ▪ Finance ▪ Sociology ▪ Strategic management ▪ Framework concepts ▪ Instrument concepts ▪ Technology, software, and methodology
	Carbon	▪ Energy ▪ Strategic management ▪ Sociology ▪ Other environmental issues ▪ Framework concepts ▪ Instrument concepts ▪ Technology, software, and methodology
Data Management	Framework concepts	▪ Strategic management ▪ Finance ▪ Sociology ▪ Other environmental issues ▪ Energy ▪ Carbon ▪ Technology, software, and methodology
	Instrument concepts	▪ Strategic management

		▪ Finance ▪ Sociology ▪ Other environmental issues ▪ Energy ▪ Carbon ▪ Technology, software, and methodology
	Technology, software, and methodology	▪ Strategic management ▪ Finance ▪ Energy ▪ Carbon

Thematic analysis of the focus group data allowed three meta-themes to emerge: strategic management, energy management, and data management. These meta-themes are conceptual themes (i.e., these themes do not represent specific data extracts) and have been derived from combining two or more content-driven themes (i.e., sub-themes coded directly from the dataset). These themes were apparent in the focus group transcript and were mentioned in some form or another by most participants.

The meta-themes identified can be related to a central theme of 'Management.' Following the thematic analysis of the dataset, it was apparent that the theme of 'Management' was discussed by most participants, with most discussions referring to some sort of management practice, commonly used business technique, or a decision-making procedure. The concept of management was referred to on numerous occasions, and strong evidence of this can be seen in the following quotations:

> *“In an ideal world, it'd be good to be able to set a budget for energy consumption. And then be able to see how master planning, or facilities management, or cultural change and all those things that we employ, how they are reducing the actual cost in line with that.” (Participant D)*
>
> *“…it allows us then to start using the data as management tools, but also, that's the strategic side of it as well.” (Participant A)*
>
> *“But doing it in a way that has longevity, and grows with the master plan, and can be tested year on year” (Participant F)*
>
> *“Well, that's the key thing is being able to monitor it and maintain the integrity of data.” (Participant B)*
>
> *“Yeah we need a baseline, we need to know when it's going above, say typical consumption” (Participant E)*

4.6 Discussing the Findings

Both Table 4-7 and Figure 4-5 demonstrate the importance of management principles in SMEs. The participants deemed management to be one of the primary factors required to engage a smaller business in carbon management. This observation aligns with the literature that states that one of the significant barriers to SMEs undertaking energy and carbon-related projects is the lack of consideration and engagement from management (UNIDO, 2011; IEA, 2017). The three overarching meta-themes and eight sub-themes identified during this study are consistent with literature review findings (refer to Table 4-5). For example, previous studies have stated that SMEs typically face barriers relating to the lack of knowledge, expertise, and awareness concerning energy efficiency and carbon management (Conway, 2015d). Whilst most participants showed an awareness, their brief knowledge was limited to a basic understanding of energy management and issues relating to carbon emissions.

4.6.1 Fiscal Matters

Managing the financial aspects of running a business is often viewed as challenging for companies of all sizes. This challenge may be more pronounced for smaller businesses, which can find it difficult to secure the necessary funding for growth. The literature, including works by Fleiter, Schleich, Ravivanpong (2012), and Kostka, Moslener, and Andreas (2013), suggests that financial constraints are a notable obstacle for small and medium enterprises (SMEs) looking to participate in Energy Efficiency (EE) and Carbon Management (CM) programs. These constraints were also echoed during the focus group discussions, where there was a noticeable lack of awareness about available funding support and a general unfamiliarity with various financing strategies. Overcoming these financial barriers, especially given the limited resources of smaller companies, is crucial. Research, including studies by UNIDO (2011) and Trianni and Cagno (2012), indicates the need for solutions to encourage SMEs to adopt EE and CM initiatives.

Additionally, companies' hesitation to allocate limited resources to unfamiliar investments is understandable, aligning with existing literature that outlines multiple risks associated with investments into energy efficiency (Painuly *et al.*, 2003; Jackson, 2010; Kleindorfer, 2011; DECC, 2014). These risks can include regulatory changes, high upfront costs, lengthy return periods, uncertainty in new technologies, and fluctuating energy prices (Hill, 2019). The participants expressed a cautious approach towards financial risks, preferring to avoid potential pitfalls in implementing energy efficiency or carbon management measures, as detailed in Table 4-6 under the thematic code ‘risk’.

4.6.2 Sociology

In small and medium enterprises (SMEs), training and education have emerged as significant factors influencing the implementation of energy efficiency programs, as noted by Trianni, Cagno, and Farné (2016). These factors notably impact the behaviours of business clients, guests, and visitors. The focus group study supports these findings, highlighting how management decisions affect various stakeholders, including guests, clients, and the company's supply chain. These decisions draw attention to the interplay between different sub-themes and their overarching management principles, particularly under the broad concept of "strategic management" and its application in sociological contexts within the industry.

While large companies often adopt corporate social responsibility (CSR) practices, as illustrated by research linking CSR to carbon management (Harwood, Humby and Harwood, 2011), SMEs have been slower to embrace CSR, as observed by Kechiche and Soparnot (2012); however, the focus group study and other research indicate a promising interest among SMEs in the social impact they can have on their stakeholders. It is also interesting to note how SMEs consider and adapt to the surrounding culture, striving to align their business operations with national and local cultural norms, as discussed by Astawa and Sudika (2014) and Graham (2014). Evidence supporting these sociological considerations within the study can be found in Table 4-6, categorised under thematic codes such as ‘behaviour’, ‘training & education’, and ‘culture’.

4.6.3 Other Environmental Issues

While the primary focus of this research is on energy efficiency and carbon management, the focus group study also brought to light broader environmental concerns. These include general sustainability, the thermal performance of business infrastructure, and water management. As outlined in the literature review (Chapter 2), carbon management encompasses various environmental issues that contribute to carbon emissions, with water management being one of these aspects. Although the greenhouse gas (GHG) emissions from water treatment and supply are relatively small compared to those from the energy sector, as pointed out by the Environment Agency (2008) and later by the UK Parliament (2020), they are still significant.

In addition to environmental impacts, the financial aspect of water management is also crucial for businesses, especially for those with high water usage or large land areas subject to surface water drainage charges. During the focus group discussions, water management was frequently mentioned as a critical part of business strategy. Participants shared insights about an alarm system used in some organisations to monitor abnormal increases in water levels, suggesting an awareness and proactive approach to managing this resource. These discussions provided valuable perspectives that could help develop carbon management practices suitable for SMEs.

4.6.4 Energy Management

The central theme of 'energy management' in this focus group study emerged from analysing two critical sub-themes: 'energy' and 'carbon'. These themes formed the primary focus of discussions, as outlined in the researcher's interview schedule (refer to Table 4-3). It became evident that even smaller companies cannot overlook the significance of energy management, given that energy consumption is an integral part of daily operations and a notable expense, as highlighted in prior studies by Önüt and Soner (2007), Fleiter, Schleich, and Ravivanpong (2012), and Hampton (2019).

The findings, detailed in Table 4-6 under the thematic code 'Energy', accentuate the relevance of energy usage in business operations, aligning with previous research on energy management in SMEs (Kannan and Boie, 2003). Despite the absence of formal energy management procedures, there was a trend among employees towards considering energy usage in the broader business strategy. Interestingly, all participants, irrespective of their job roles, demonstrated some level of understanding of energy matters, although the depth of this knowledge varied.

In contrast, the topic of carbon and related issues appeared less familiar to participants, aligning with the actuality that carbon management is a relatively new field, especially when compared to energy management. Literature reveals significant barriers for SMEs in this area, including limited knowledge, resources, and in-house expertise (Hendrichs and Busch, 2012a; Conway, 2015d). The little academic literature on carbon management in SMEs further contributes to this knowledge gap. Additionally, this study observed that SMEs often do not recognise the potential benefits, with constraints such as time, expertise, and financial resources discouraging them from pursuing advancements in this area.

4.6.5 Technology, Software, and Methodology

The sub-theme 'technology, software, and methodology' encompassed a range of topics that, although not extensively addressed individually, collectively yielded some noteworthy insights. Previous studies, such as those by Hendrichs and Busch (2012a), have highlighted the complexity of environmental guidelines and standards, which can be excessively intricate for small and medium enterprises (SMEs).

A key suggestion that emerged during discussions was developing a user-friendly guide or informational document on carbon management. Such a resource could simplify concepts of carbon management for a general audience, helping SMEs understand the benefits and identify potential energy efficiency measures to reduce energy use and associated costs while lowering carbon emissions.

Although participants mentioned various renewable energy technologies in use at their businesses, like biomass boilers, solar photovoltaic arrays, and micro-hydroelectric power stations, a general need for deeper understanding was apparent. One participant proposed using marginal abatement cost curve (MACC) analysis as a practical tool for evaluating carbon reduction measures, indicating an interest in more advanced methods for assessing energy and environmental initiatives.

4.6.6 Framework & Instrument Concepts

Hendrichs and Busch (2012a) introduced a seven-step carbon management framework for SMEs, exemplified through a Swiss manufacturing company case study. This framework aligns with several findings from the focus group. Firstly, the pivotal role of management commitment in implementing a successful project, echoed by participants of the focus group, was emphasised. Participants also highlighted the need for methodologies and frameworks that are easily understandable and intuitive for all employees, not just management (see Table 4-6, thematic code 'Framework & Model').

Secondly, Hendrichs and Busch (2012a) highlighted the importance of motivating all staff members to use a carbon management strategy. This idea resonates with the diverse operational contexts of SMEs discussed during the focus group. Additionally, their third recommendation for a flexible, adaptable framework is indirectly supported by the participants' references to the varied nature of operations within SMEs.

A key insight from this research is the necessity for any new carbon management strategy or framework to align with a company's existing master plan, ensuring a symbiotic relationship. The focus group also suggested the value of a cost-benefit analysis to clearly demonstrate the benefits and added value. One participant noted the benefit of integrating energy and carbon data into existing key performance indicators (KPIs), maintaining its relevance to the company's ethos.

Regarding tools for effective carbon management, suggestions from participants included a dashboard to integrate and display energy, carbon, and cost data, aiding in performance assessment. They emphasised the importance of establishing a baseline, aligning with methodologies like the GHG Protocol (WBCSD and WRI, 2004), which advocates for defining a base year for emissions tracking. Furthermore, the idea of a mobile app for easy data access and a user-friendly interface was discussed, along with the potential addition of a forecasting feature to predict the impact of future implementations on business KPIs.

4.7 Study Limitations

Several critical factors were considered in initiating a preliminary investigative study to develop a new carbon management framework. The primary aim was to gather innovative ideas from industry experts to inform the development phase (detailed in Chapter 3 in Section 3.2). However, time constraints posed by the university's research schedule significantly limited the study's scope. Additionally, collaborating with an industrial partner, who also partially sponsored the research, required that the outcomes directly benefit the company.

Given these conditions, a focus group study was the most efficient approach to achieve the desired outcomes. The study invited participation from both employees of the industrial partner and external experts. However, this methodology had its limitations. Due to time constraints, only one focus group was conducted. While there are varying opinions on the optimal number of focus groups for a study (Guest, Namey and Mckenna, 2017), and some research emphasises the importance of reaching data saturation (Krueger and Casey, 2000), the decision to conduct a single session may have constrained the diversity and depth of findings. In future research, increasing the number of focus groups could be beneficial to ensure more comprehensive data collection.

Furthermore, a case study could have enhanced the quality of data from the focus group (Breen, 2006), but time limitations and the small size of the target population made this impractical. Participants were encouraged to seek clarification on unclear questions to mitigate these limitations. Another limitation was the composition of the study population. Out of ten candidates approached, five from the industrial partner and five externals, only one external participant joined, potentially limiting the variety of perspectives and influencing the study's outcomes.

The researcher's limited background in qualitative research could have influenced the design, execution, and analysis of the study. This lack of experience highlighted several learning opportunities, particularly in participant selection, the interview schedule's design, and the focus group's facilitation. Successfully moderating a focus group requires skill in appropriately framing questions, fostering an open discussion environment, and maintaining neutrality, all honed through experience. This study has been a valuable step in developing these competencies.

4.8 Chapter Summary

This chapter detailed the focus group study to explore how small and medium-sized enterprises (SMEs) perceive energy and carbon management practices. The study aimed to understand SMEs' awareness of carbon management and energy efficiency, highlighting gaps in their knowledge and practices. The guiding research question sought to delve into the mindset of typical SME employees regarding these topics.

Key to the study was identifying the challenges SMEs face in adopting carbon management practices despite the availability of information on energy efficiency and emissions reduction. The study aimed to discover why SMEs often view engaging in carbon management as daunting and what could be done to encourage their participation.

The focus group findings revealed three central meta-themes: Strategic Management, Energy Management, and Data Management, each comprising various sub-themes. These themes provided insights into the complexities of managing carbon emissions within SMEs, including aspects of financial management, sociology, environmental issues, and the use of technology.

These findings significantly influenced the subsequent development of a novel carbon management framework tailored toward SMEs, discussed in the following chapter. This framework was designed to align with the identified strategic, energy, and data management themes, aiming to be a practical, effective, and user-friendly tool for SMEs.

The chapter also highlighted the need for additional tools to aid SMEs in collecting and analysing operational carbon assessment data, as expressed by focus group participants and other key stakeholders. Consequently, the development of two supporting tools was initiated, which are delineated in Chapter 5. This focus group study thus served as a foundational step in creating a comprehensive carbon management framework and supporting tools, addressing the specific needs and challenges of SMEs in the realm of carbon management.

CHAPTER FIVE

5. The Development of a Carbon Management Framework

5.1 Chapter Overview

This chapter delves into the primary research output: developing a novel carbon management framework. This framework results from insights from the preliminary investigative study detailed in Chapter 4. The chapter aims to articulate the rationale behind the framework's development, focusing on how the intended target user was identified and the choices made to ensure the framework's applicability and effectiveness.

The framework's development is justified through a thorough examination of the findings from both the focus group study and academic literature. This chapter explains the methodological approach applied during the framework's development, justifying each decision. Also detailed is the development process itself, highlighting any challenges or limitations encountered and how they were addressed.

Finally, the chapter details the framework's evolution through its various stages of development, examining its maturity over time and discussing the three crucial iterations in response to the materiality assessment and feedback from prospective end-users and research stakeholders.

5.2 Rationale for Framework Development

5.2.1 The Philosophical Approach and Theoretical Framework

Inspired by the renowned philosopher John Dewey, a leading figure in pragmatism (R. W. Sleeper, 2001), the researcher adopted a practical approach to address the following research objectives:

Objective 1. To comprehensively review current literature and identify knowledge gaps.

Objective 2. Utilise qualitative methods to obtain in-depth insights from industry experts about the challenges and drivers for SMEs in carbon management.

Objective 3. Ensure the research methodology is pragmatic, particularly through collaboration with industry partners.

Objective 4. Develop a systematic process for SMEs to implement carbon management practices.

Objective 5. Apply the findings and outputs of the research to a practical, real-world case study.

As Dewey (1908) pragmatism emphasises the practical utility of knowledge and links the truth of ideas to their effectiveness in achieving desired results. Utilising Dewey's 5-step model of inquiry (depicted in Figure 5-1), the initial stages of the research involved identifying and exploring the problem, as undertaken in Chapters 2 and 4, respectively.

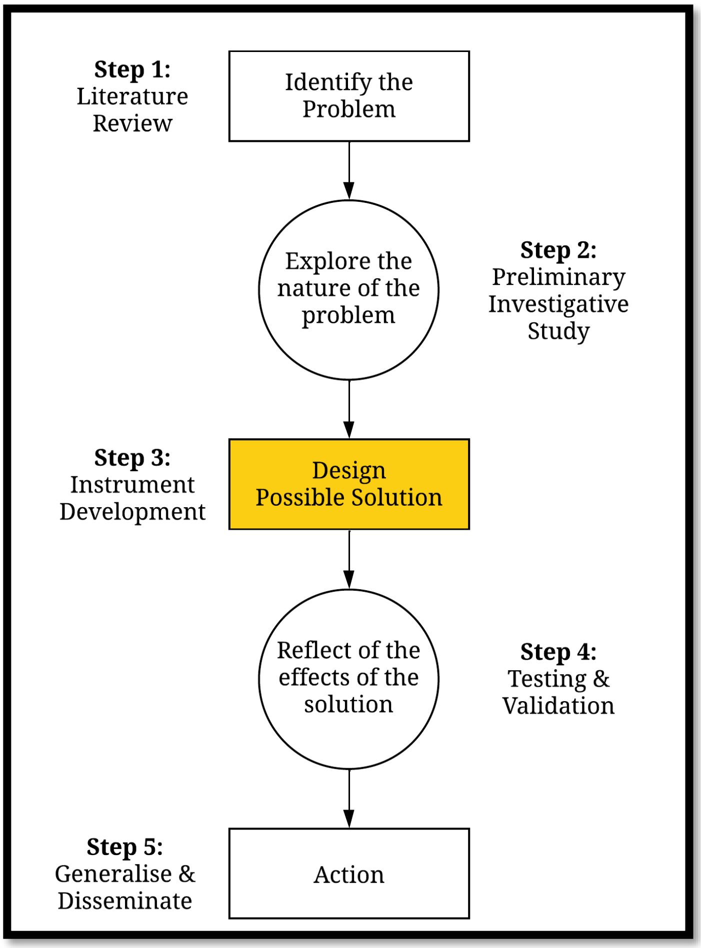

Figure 5-1. John Dewey's Five-Step Model of Inquiry (Adapted from Morgan, 2014a)

5.2.2 Identifying the Problem

The literature review (Chapter 2) highlighted the significant flaws in current government policies (section 2.3.3) and the oversight of SMEs in the UK's business emissions accounting (Mole and Belt, 2023). With SMEs representing 99.9% of all UK businesses, contributing over half of the nation's turnover (DBT, 2023), and accounting for 29-36% of total emissions (British Business Bank, 2021), their role is crucial in national emission reduction efforts. Despite potential benefits like cost savings and enhanced reputation (Conway, 2015b; Hoogendoorn, Guerra and van der Zwan, 2015b), SMEs face barriers in implementing carbon management, such as limited knowledge and resources and a tendency to undervalue environmental initiatives (Hendrichs and Busch, 2012c; British Chamber of Commerce, 2021).

The researcher proposes that there may be opportunities for refinement in UK government policies to provide more viable solutions for business emissions reduction. Furthermore, it is suggested that SMEs could benefit from more customised guidance and frameworks to enhance their carbon management efforts. In response to these possible needs, this thesis endeavours to contribute a framework focused on carbon management within SMEs, particularly in medium-sized organisations (discussed in more detail in Section 5.2.4). This framework aims to offer strategies that might help reduce carbon footprints and guide their potential implementation.

5.2.3 Explore the Nature of the Problem

Adopting a mixed-method research approach, the researcher used the Exploratory Sequential Design: Instrument Development Model (Figure 5-2, adapted from Creswell and Plano Clark, 2007). This design choice fits well with the theoretical framework adopted (see Figure 5-1) as a practical approach to addressing the research gaps identified in Chapter 2.

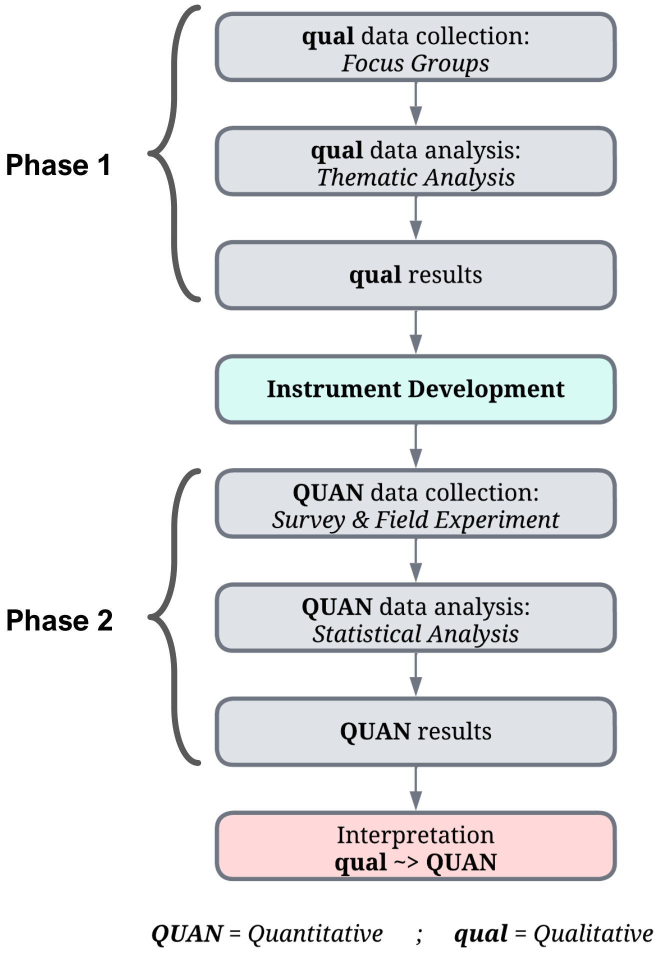

Figure 5-2. Exploratory Sequential Design: Instrument Development Model - Adapted from Creswell and Plano Clark (2007b)

In Phase 1, an exploratory qualitative study conducted through a focus group (Chapter 4) investigated SME perceptions of energy and carbon management. The study aimed to uncover SMEs' challenges in adopting these practices and understand their reluctance to implement them. The study also gained participants' insights on suitable instruments, tools, and methodologies for supporting SMEs in carbon management projects. Section 4.5 details these findings, and Section 4.6 discusses the concepts further. The study revealed three meta-themes: Strategic Management, Energy Management, and Data Management. Participants emphasised the need for methodologies and frameworks that are intuitive, flexible, and adaptable across various business sectors. Consequently, combined with the literature review gaps, the researcher concluded that a carbon management framework would be the most effective solution to the identified problems.

5.2.4 Intended Target-User

Developing a framework necessitated a clear understanding of the target audience. While larger corporations frequently face regulatory mandates requiring them to integrate carbon management practices, compelling their engagement in sustainable business operations, SMEs often do not encounter such compulsory directives (Conway, 2015e). This notable disparity in regulatory expectations and the knowledge gaps identified in Chapter 2 prompted the research to concentrate on SMEs specifically. Recognising this gap, the study aimed to delve deeper into this business category, acknowledging the need for more tailored carbon management strategies and tools.

Since SMEs represent a significant portion of the UK business landscape, accounting for 99.9% of all businesses (as showed in Table 5-1, adapted from DBT, 2023), identifying the end-user became a crucial step in the framework's development. This focus allowed the research to address the most relevant needs effectively.

The UK Government categorises an SME as any organisation with fewer than 250 employees, an under €50 million turnover, or a balance sheet total of less than €43 million (UK Gov, 2022b). Given the diversity and sheer number of SMEs, approximately 5.5 million, designing a one-size-fits-all framework would be an immense challenge. Therefore, the researcher believed a more focused approach would likely produce a practical and testable outcome.

Table 5-1. 2022 UK Business Population

Business Size	No. of Organisations	Proportion of UK Businesses
All businesses	5,508,935	100%
SMEs (0-249 employees)	5,501,260	99.9%
No employees	4,061,035	73.7%
1-9 employees	1,187,045	21.5%
10-49 employees	217,240	3.9%
50-249 employees	35,940	0.7%
250 or more employees	7,675	0.1%

5.2.4.1 Narrowing the Focus – Medium-sized Entities

Knowsley Safari, a zoological safari park in Merseyside, UK, and the sponsoring company for this research influenced the project's direction. Their commitment to understanding and reducing environmental impact positioned them as an ideal case study. Knowsley Safari's diverse operations include animal enclosures, an amusement park, restaurants, offices, an auditorium, and a conference centre, all situated within a large nature reserve. Classified as a medium-sized organisation in the Arts, Entertainment, and Recreation sector - as per UK Government's standard industrial classifications (UK Government, 2018), Knowsley Safari's unique business model provided a valuable framework for defining the intended target user.

This industry collaboration offered a distinctive opportunity to design, develop, and test the proposed research framework in a real-world setting. Consequently, the framework and supporting tools were tailored to cater to medium-sized companies, typically with 50-249 employees, comprising 35,940 organisations in the UK in 2022 (UK Gov, 2022a).

5.3 Instrument Development Process

The instrument development process involved understanding the needs and requirements of the end-user, as it needed to be utilised and operated by the layperson. For each instrument, an iterative approach was taken, whereby developments and adaptations were made based on industry discussions, new research findings, and a peer-review process. The researcher defined an instrument development process (see Figure 5-3) to ensure all required steps were taken during the creation of the carbon management (CM) framework.

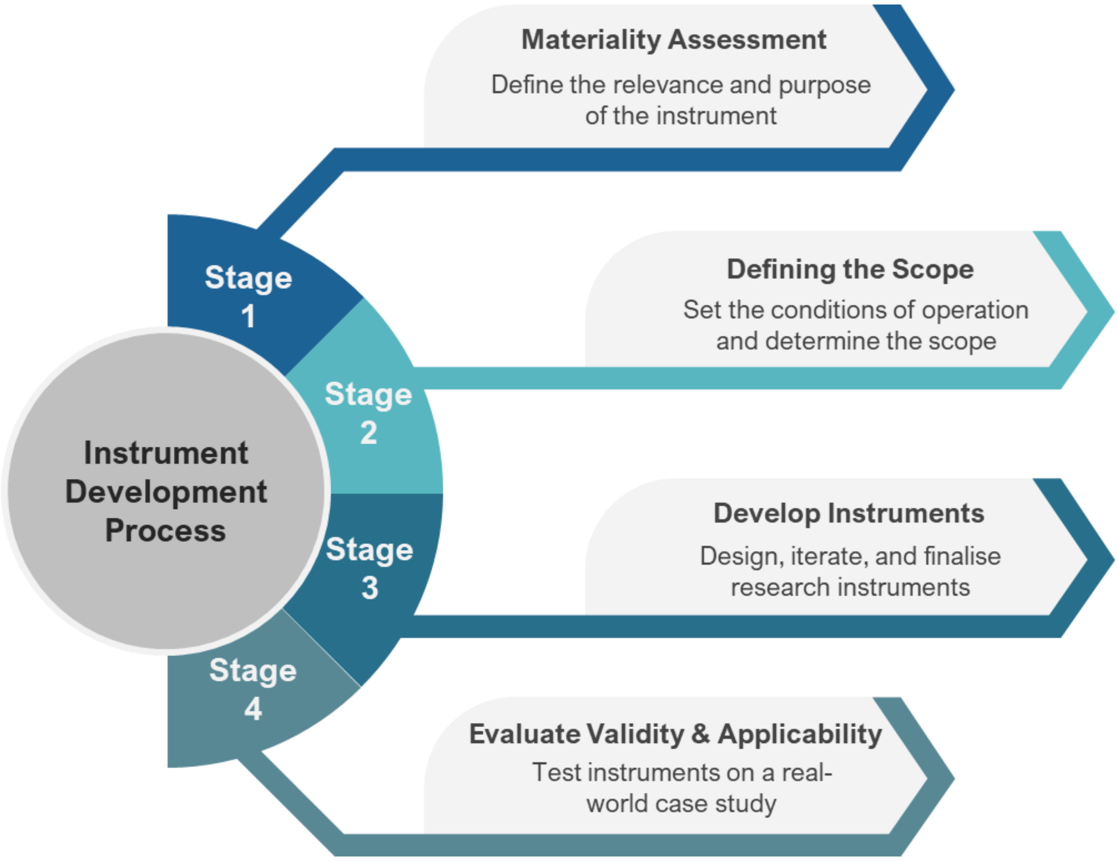

Figure 5-3. Instrument Development Process

5.3.1 Stage 1: Materiality Assessment

The first stage assessed the materiality of carbon management practices for SMEs. The concept of materiality classifies what information is relevant (Lynne Phelps and Rigling Gallagher, 2016; A. Adams et al., 2021; GRI, 2022) and, in the context of instrument development, defines who the intended user is. It is widely used in sustainability and the growing area of environmental, social, and governance (ESG), a subset of non-financial performance indicators (Escrig-Olmedo *et al.*, 2010). Materiality can vary depending on the application and who is interpreting the information presented; this means the concept can be subjective. In the case of this research, to overcome any bias during the materiality assessment, the instruments were peer-reviewed during development. The peer-review team comprised the research project sponsor (Knowsley Safari) and academic professionals within the researcher's university. A materiality assessment process was established, shown in Figure 5-4.

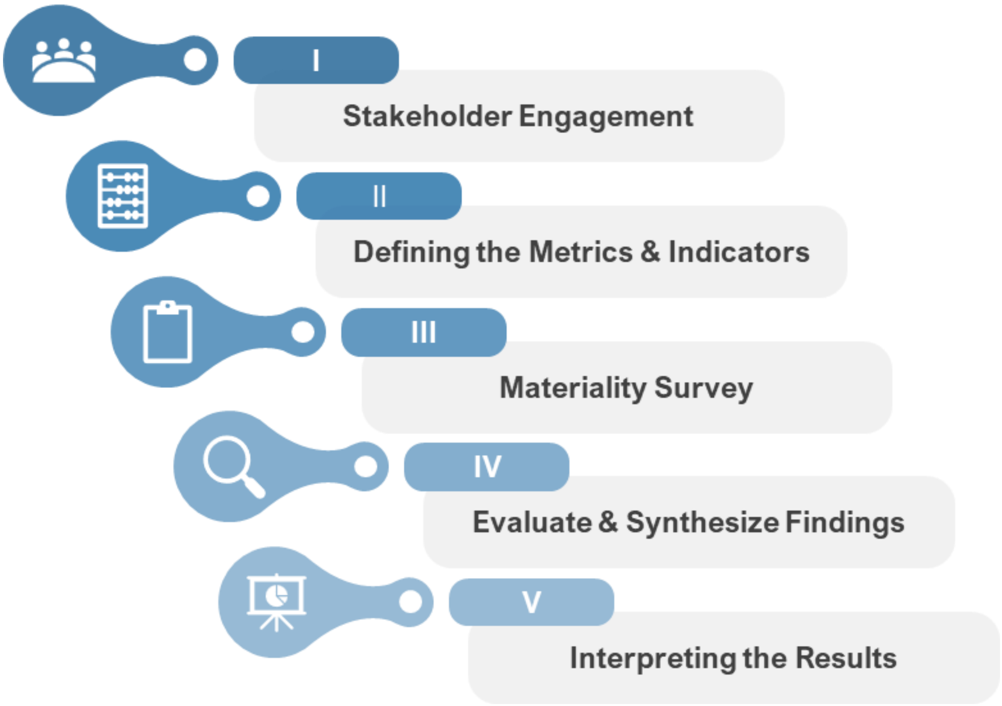

Figure 5-4. Materiality Assessment Process

5.3.1.1 I: Stakeholder Engagement

A materiality assessment is a process aimed at engaging relevant stakeholders to determine the importance of specific issues. The insights gained through this assessment were used to create the framework and ensure the core purpose aligned with the end-user's needs. It was essential first to identify the relevant stakeholders for whom the instruments were developed. In the case of this research project, the industrial partner (Knowsley Safari) fits within the intended target-user defined (see section 5.2.4). Therefore, employees of the industrial partner were contacted as the first port of call. In addition, the researcher decided it would be essential to have a varied group of stakeholders, approaching several academic peers to provide additional insights into the instrument development process. Once the stakeholders were identified, approached, and accepted the invitation, the materiality assessment group was established and remained consistent for each stage of instrument development.

During the materiality assessment, stakeholders were approached as groups and individuals; casual discussions were held with each stakeholder at various points during the framework development. However, there was no formal arrangement for these conversations, as the researcher felt that a more casual setting would offer the most organic opinions and provide a rich pool of information.

To collect more meaningful and valuable information, the researcher designed a questionnaire to gather opinions on materiality and help guide the focus. Table 5-2 below lists the group of stakeholders involved in the materiality assessment; names have been anonymised for data protection with stakeholders assigned a unique ID, job titles are stated for clarity, and a note to state whether it is an internal stakeholder (academic researcher based within the researcher's university) or external stakeholder (employee of industrial partner) is included.

Table 5-2. Materiality Assessment Stakeholder Groups

Stakeholder ID	Job Title	Internal/External
EFM	Facilities Manager	External
EPM	Property Manager	External
EOM	Operations Manager	External
ERA	Researcher	External
ERB	Researcher	External
ILA	Lecturer	Internal
ILB	Lecturer	Internal
IRA	Researcher	Internal

5.3.1.2 II: Defining the Metrics & Indicators

After identifying the stakeholders, it was essential to determine the sustainability metrics and indicators. This process was relatively straightforward, given the researcher's focus on climate change adaptation. However, sustainability encompasses various metrics, from clean energy, water use, and greenhouse gas (GHG) emissions to preventing global poverty, improving education, and reducing waste. The United Nations (UN) defines seventeen metrics that make up the UN Sustainable Development Goals (SDGs) (United Nations, 2023a). In 2015, 'the 2030 Agenda for Sustainable Development' was adopted by all UN member states (this was 193 countries in 2015), outlining the 17 SDGs and 169 targets aimed at encouraging action in "areas of critical importance for humanity and the planet" (United Nations, 2015). The UN SDGs provided the starting point for determining the sustainability metrics and indicators, providing the grounding for the development of the framework.

As the intended target user was medium-sized enterprises operating in the UK, further refinement of sustainability metrics was required, and it was discussed with stakeholders that the research focus should be narrowed to deliver a more concise, effective, and beneficial outcome.

This research's primary focus was the adaptation and mitigation of climate change and the impact that UK business emissions have on global warming. Taking ideas from the focus group study (refer to Chapter 4) and combining them with the UN's SDGs enabled the researcher to deduce the metrics and indicators that are assumed material to the stakeholders.

With a predominant focus on climate change, several indicators were identified as potentially significant. First, the relevant SDGs were identified:

- *SDG 4 - Quality education*
- *SDG 7 - Affordable and clean energy*
- *SDG 9 - Industry, innovation, and infrastructure*
- *SDG 11 - Sustainable cities and communities*
- *SDG 12 - Responsible consumption and production*
- *SDG 13 - Climate Action.*

Following this, it was essential to understand how the SDGs identified could relate to carbon management within SMEs based in the UK. As previously mentioned, the core principle of the framework was for medium-sized businesses to mitigate against climate change. This principle meant understanding, accounting, and reducing GHG emissions generated from business activities. According to *'The Greenhouse Gas Protocol: A Corporate Accounting and Reporting Standard,'* emissions can be categorised into three scopes (WBCSD and WRI, 2004):

- **Scope 1** emissions are the direct emissions that business activities create, like the fuel used in vehicles, or the gas and fuels used to provide heating and hot water to buildings.
- **Scope 2** emissions are indirect emissions from electricity production procured by a business to provide power to operations.
- **Scope 3** emissions are the indirect emissions from all other activities businesses engage in, including the emissions associated with the products and services procured or the energy used to process the water consumed and the waste generated.

Scope 1 and 2 emissions are often referred to as operational emissions, as they result from activities that occur within a business's operation. Large corporates have reported these emissions for several years, as specific UK legislation (discussed in Chapter 2) mandates large companies to account for and report on their scope 1 and 2 emissions (BEIS *et al.*, 2021). However, SMEs have typically been excluded from any legislation, and so, therefore, a lack of carbon management practices exists within organisations of a smaller size. Scope 3, on the other hand, has been ignored for many years, and it is only recently[1] that we have seen an upward surge in large corporations reporting on emissions from their value chain. Despite the increase, there is still a long way to go with scope 3 accounting. The researcher believes that significantly more investment is required from both governments and industry if this is to make a substantial impact on global emissions.

Combining the UN SDGs with the three emissions scopes, instrument metrics were identified (shown in Table 5-3), and these were to be further refined through discussions with research stakeholders.

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[1] *As of 2022*

Table 5-3. Instrument Development Metrics

Metrics	**Sub-Metrics**
Energy	Electricity; Liquid fuels; Solid fuels; Gaseous fuels; Renewables; Low-carbon fuels; Fossil fuels
Infrastructure & Buildings	Offices; Residential; Retail; Hospitality; Storage; Multi-purpose; Gathering buildings; Educational; Industrial; Sports & Recreation; Agriculture
Goods & Services	Direct procurement; Indirect procurement; Water; Energy; Circular economy; Supply Chain; Upstream & Downstream
Carbon Emissions	Carbon; Direct emissions; Indirect emissions; Scope 1; Scope 2; Scope 3; Embodied carbon; Upfront carbon; Whole life carbon; Operational; In-use
People and Behaviour	Behaviour; Culture; Training & Education; Operations; People; Building interaction

5.3.1.3 III: Materiality Survey

The instrument development metrics, shown in Table 5-3, were identified as material to the core principle of climate mitigation within the UK business. However, it was still a broad set of indicators that would provide a significant challenge during the development of instruments. The next step in the materiality assessment involved designing a questionnaire survey and focused on gaining insights from the stakeholder group on the materiality of each metric and sub-metric. The questionnaire survey asked stakeholders to rank the importance of the five key metrics identified:

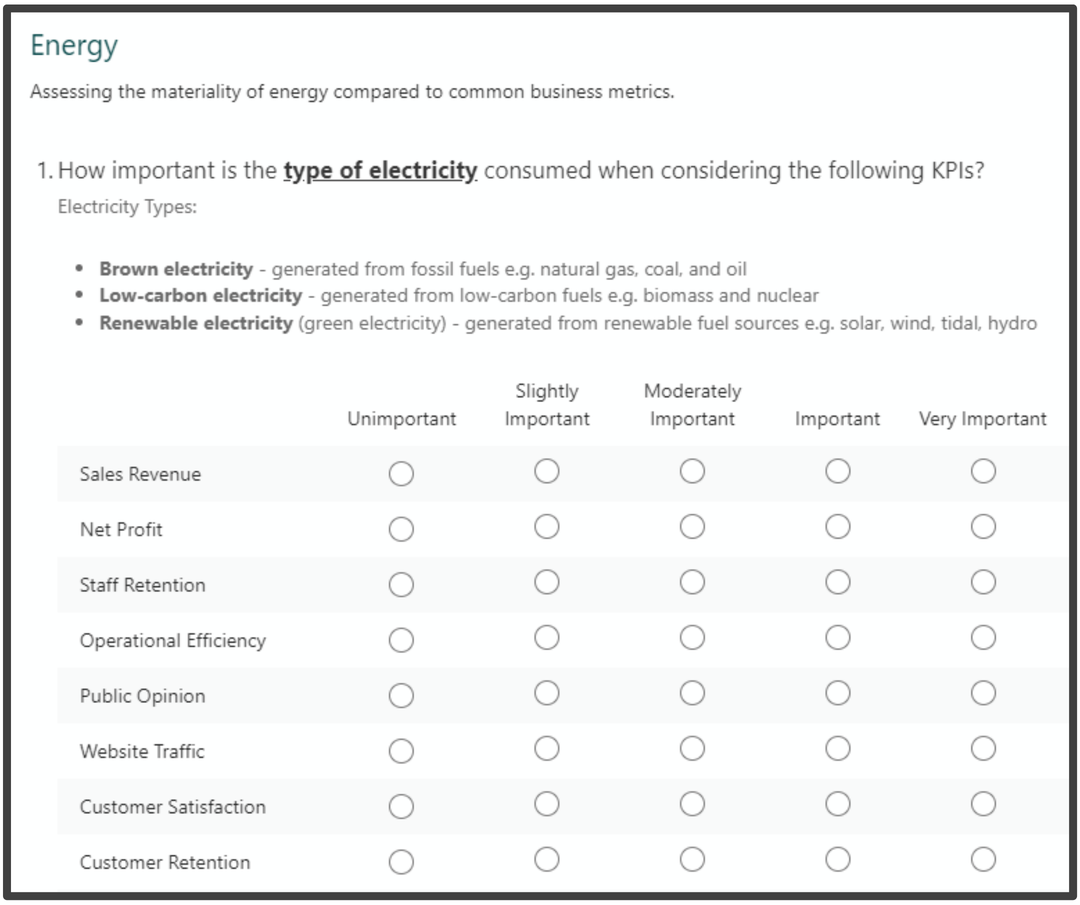
- Energy
- Infrastructure & Buildings
- Goods & Services
- Carbon Emissions
- People and Behaviour

These key metrics were ranked on their importance with common key performance indicators (KPIs), as shown in Table 5-4. The chosen KPIs were established from the focus group findings, where study participants highlighted some of the more critical issues businesses are concerned with (see Chapter 4 for complete analysis).

Table 5-4. Instrument Development KPIs

Business Area	**KPI**	**Definition**
Financial	Sales revenue	The income received from selling products or services before any deductions are applied.
	Net profit	The income (or profit) made once expenses, interest, overheads, taxes, depreciation, and amortisation have been deduced from the total sales revenue.
Operational	Staff retention	The ability to retain employees for an extended period. This could also be considered staff turnover, meaning the number of employees leaving the business and being replaced by others.
	Operational efficiency	A metric used to measure resource allocation or the ability to reduce resources, production time, effort, and materials as much as possible whilst retaining quality and increasing profits.
Marketing & PR	Website traffic	Used to track the number of people who visit a company's website. A useful metric that can be used to measure marketing performance.
	Public opinion	The collective views that define how people perceive a certain company.
	Customer satisfaction	A measure of how goods or services sold by a company meet or exceed customer expectations. This KPI is commonly used in marketing to understand the needs and demands of their clientele.
	Customer retention	The ability to retain a customer's loyalty to a company. Repeat customers will help a business to improve its reputation and increase its sales revenue year-on-year.

The questionnaire survey was sent to the stakeholders for their responses. Each question followed an identical format where questions used a 5-point Likert scale, allowing respondents to express their opinions on the importance of a specific metric with the KPIs identified (see Table 5-4 for list of KPIs). Three questions were asked for each of the five key metrics (totalling fifteen), each focussing on a different sub-metric to ensure a broad range of topics were covered. Each question asked the respondent to rank the importance of a specific sub-metric against the eight KPIs; Figure 5-5 shows an example question; the complete questionnaire survey can be found at the following link: https://forms.office.com/e/vUBQtb6NYg



Energy

Assessing the materiality of energy compared to common business metrics.

1. How important is the **type of electricity** consumed when considering the following KPIs?

Electricity Types:

- **Brown electricity** - generated from fossil fuels e.g. natural gas, coal, and oil
- **Low-carbon electricity** - generated from low-carbon fuels e.g. biomass and nuclear
- **Renewable electricity** (green electricity) - generated from renewable fuel sources e.g. solar, wind, tidal, hydro

	Unimportant	Slightly Important	Moderately Important	Important	Very Important
Sales Revenue	○	○	○	○	○
Net Profit	○	○	○	○	○
Staff Retention	○	○	○	○	○
Operational Efficiency	○	○	○	○	○
Public Opinion	○	○	○	○	○
Website Traffic	○	○	○	○	○
Customer Satisfaction	○	○	○	○	○
Customer Retention	○	○	○	○	○

Figure 5-5. Example question format from materiality survey

5.3.1.4 IV: Evaluate and Synthesise Findings

The questionnaire survey produced quantitative results that could be easily scored and analysed using a combination of descriptive and inferential analytics. Rational and critical thinking was applied to the data to identify patterns in the stakeholders' responses. Firstly, the raw data was prepared by importing it into Microsoft Excel (the chosen statistical analysis software), where it was then checked for any errors or discrepancies. Once checked, the data was synthesised into three groups: Key Metrics, Sub Metrics, and KPIs. This made the raw data more accessible to analyse and draw conclusions. A 1-5 scoring system was established and applied to the results, as shown in Table 5-5 ; this helped to quickly identify which key and sub-metrics were most material as ranked by the stakeholder group. The respondents were asked to rank each sub-metric by its importance against each of the KPIs indicated (see Table 5-4), with a score assigned for each level of importance. Scores were subsequently summed for each of the three groups, allowing for quantitative analysis of the findings and providing exciting results that helped guide the development of instruments.

Table 5-5. Materiality Assessment: Levels of Importance Scoring System

Level of Importance	Scoring Points
Unimportant	1
Slightly Important	2
Moderately Important	3
Important	4
Very Important	5

When evaluating results from the materiality survey, it was first important to compare the materiality of the key metrics (see Table 5-3). Results showed there was not a significant amount of variance between the five key metrics, with 'People & Behaviour' and 'Infrastructure & Buildings' proving the most important overall, followed by 'Carbon Emissions,' 'Goods & Services' and 'Energy' (in descending order of importance). The key metrics formed each section of the materiality survey, where three questions were asked for each. Figure 5-6 highlights the total points obtained from each section. Whilst it provides a ranking for each key metric, it does not provide much information to support the development of CM framework. As discussed in section 5.3.1.2, the key metrics were obtained through literature research and findings from the focus group study. Therefore, it is of less concern to rank the importance of the key metrics, as it was determined that they are all of some importance.

Instead, the primary focus of this materiality assessment was to help the researcher refine the process of developing a carbon reduction and mitigation framework with UK-based SMEs, specifically medium-sized businesses (refer to section 5.2.4). To achieve this, the questions in the survey were specifically designed to extract information on the importance of the sub-metrics and KPIs.

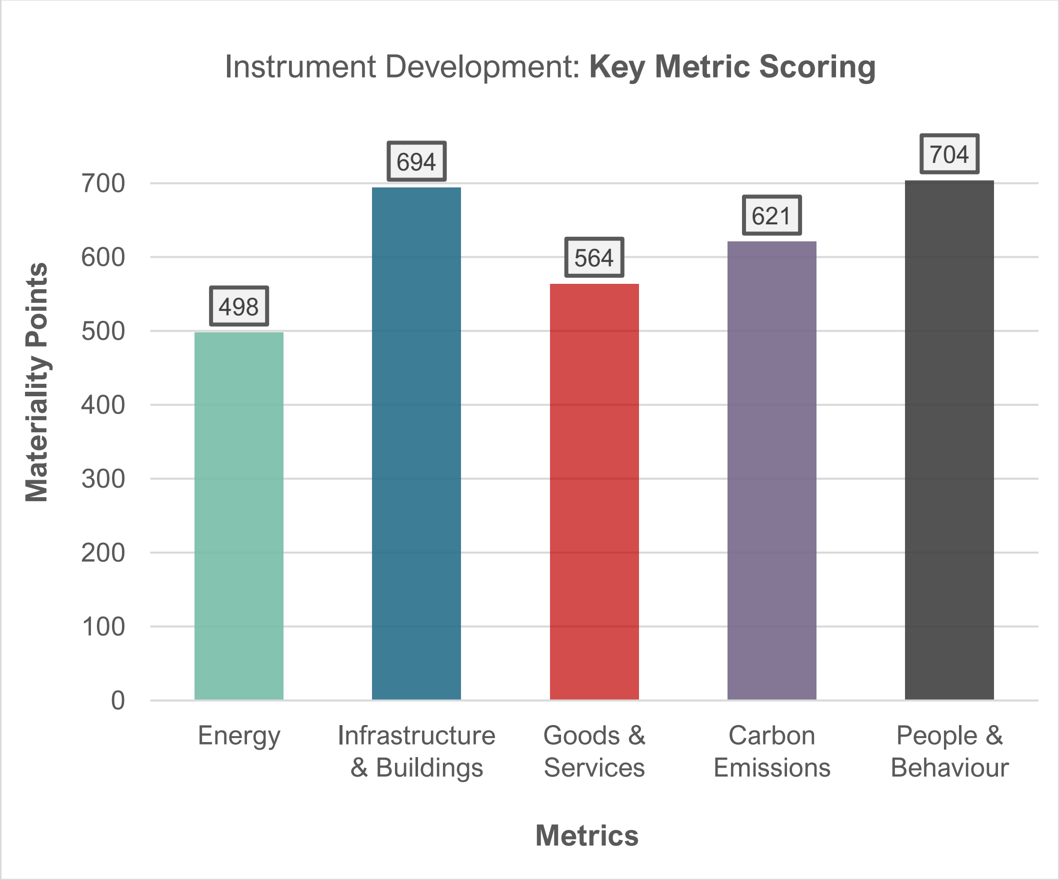


Figure 5-6. Instrument Development Key Metrics: Materiality Assessment Scoring

Evaluating results for the sub-metrics provided some interesting insights and helped the researcher further understand which areas of business activities are of greater importance. Figure 5-7 ranks the importance of each sub-metric; for reference, each had a specific question asking respondents to rank the level of importance. Synthesis of the results at this stage was measured across all eight KPIs (see Table 5-4) and summed to indicate the most critical business activities or sub-metrics as they have been referred to. To highlight some key findings, all sub-metrics that scored over 200 materiality points were classified as essential and, therefore, must be considered when looking to mitigate and reduce carbon emissions. The sub-metrics scoring over 200 materiality points are as follows (in descending order from most important to least important):

- *Environmental impact of goods & services sold.*
- *Educating customers on carbon management.*
- *Ensuring buildings & infrastructure are maintained frequently.*
- *Considering the interaction between a building and its occupants.*

- *Measuring & reporting operational carbon.*
- *Integrating the concept of Net-Zero Carbon within business models.*
- *Increasing and maintaining the thermal performance of buildings.*
- *Maintaining the efficiency of equipment & machinery.*
- *Training and educating employees on any new policies or operating procedures working toward carbon reduction.*

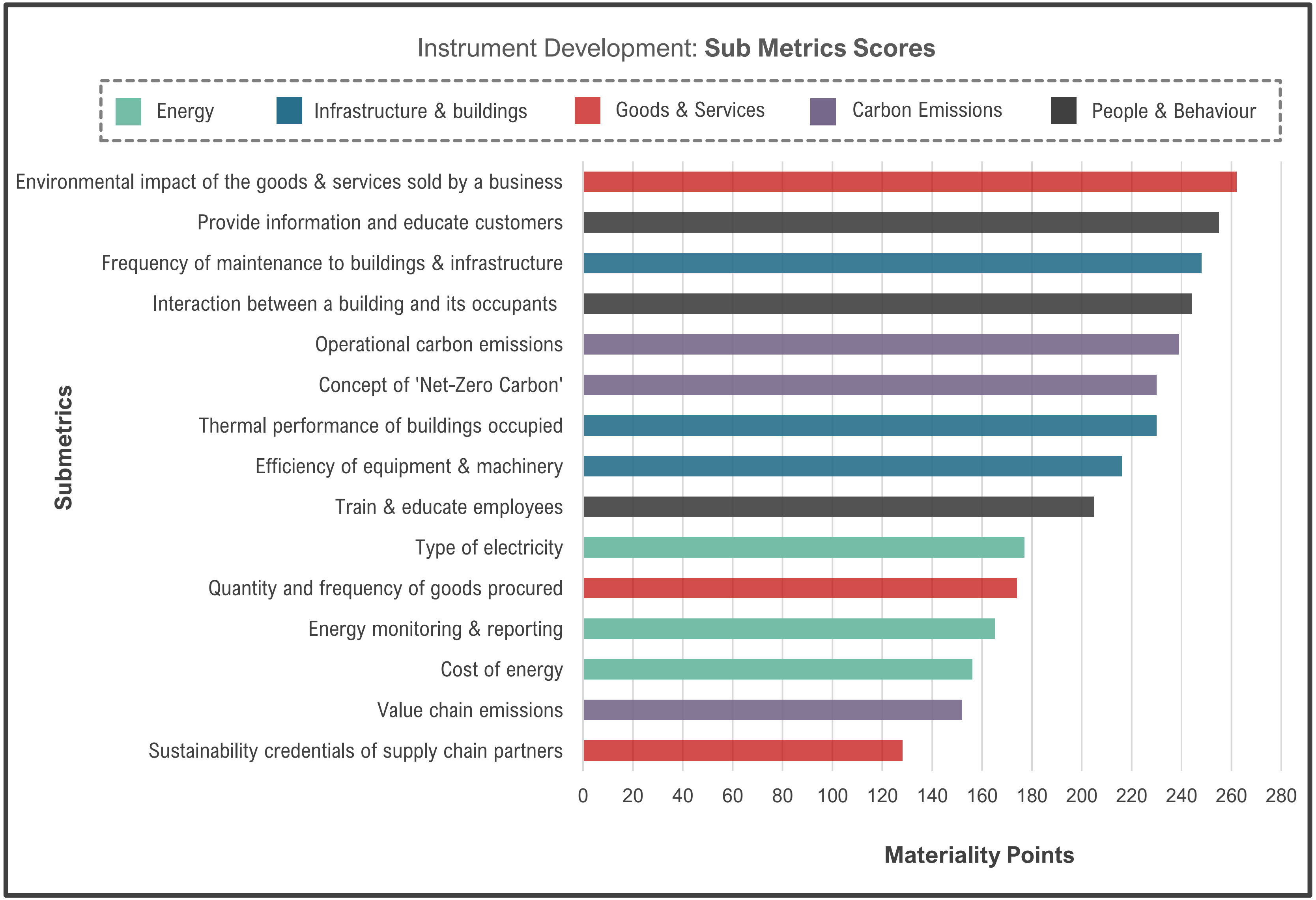


Figure 5-7. Instrument Development Sub Metrics: Materiality Assessment Scoring

5.3.1.5 V: Interpreting the Results

Once an assessment ranking the importance of each sub-metric across all eight KPIs had been completed, further analysis took place to understand how each sub-metric stacked up against the individual KPIs. Some key findings from the analysis are discussed in the following section, in addition to a series of charts created for each of the KPIs to display a graphical representation of the survey findings. Tables containing all the raw data for this additional synthesis and data analysis can be found in *Appendix C1 – Materiality Assessment*

It is essential to revisit and understand the scoring system applied when interpreting the findings from Figure 5-8 to Figure 5-15. Each sub-metric was scored on its level of importance for each of the KPIs, and 1-5 points grading system was applied (1 = least importance and 5 = most important). The materiality survey was sent out to eight stakeholders (identified in section 5.3.1.1) and received a 100% response rate, meaning the maximum score for each sub-metric against each KPI was 40 points (as shown in the equation below).

$$Total\ available\ points\ per\ KPI = No. Respondents\ x\ Max. points\ available$$
$$= 8\ x\ 5$$
$$= \mathbf{40\ points}$$

It is important to note, that whilst findings from this materiality survey show interesting results, a strong bias can be assumed due to the small sample size of *'cherry-picked'* stakeholders. As discussed in section 5.3.1.1, stakeholders were chosen due to their interest in the project and affiliation with either the industrial partner or the university. Therefore, caution must be applied when interpreting the results of this materiality survey. Despite that, the industrial partner and the relevant stakeholders involved were the predominant drivers behind the development of CM instruments, so that must also be considered.

Sales Revenue [Figure 5-8]

When considering *sales revenue* as a KPI, respondents thought that maintenance of owned and controlled assets was vital, whilst energy procurement and management were of little relevance when concerned with *sales revenue*. A further interesting observation showed that whilst operational carbon and the concept of net-zero was deemed important in increasing sales revenue, value chain activities (or scope 3 emissions) are of little concern.

Net Profit [Figure 5-9]

Following a similar trend to sales revenue, respondents ranked operational carbon substantially more critical than value chain carbon when looking to increase net profit. The researcher believes this is due to operational carbon (scope 1 & 2 emissions) being emitted directly from activities controlled by the business, whilst value chain (scope 3) emissions occur from indirect activities controlled by a third party. Not surprisingly, the cost of energy and the procurement of goods scored highly when considering net profit as a KPI. What is possibly more surprising is that energy monitoring and reporting were of the least importance despite the apparent correlation between the two.

Staff Retention [Figure 5-10]

Sub-metrics relating to buildings, including maintenance, thermal efficiency, and interaction, all scored highly when considering staff retention as an important business indicator. It is assumed that this is due to most workers valuing a comfortable and friendly environment to work in. An additional observation showed that all sub-metrics within the 'people & behaviour' metric category scored highly on the level of importance, with training and education of employees and customers seemingly important when looking to retain a company's workforce. Furthermore, net-zero and operational carbon emissions received a relatively high importance score within staff retention.

Operational Efficiency [Figure 5-11]

Not surprisingly, when considering operational efficiency as a KPI, responses from the materiality survey highlighted that the maintenance of buildings, infrastructure, equipment, and machinery was essential. This makes common sense, as any downtime or closure of a company's assets would limit the ability to operate efficiently. Respondents also indicated that its supply chain partners' sustainability credentials and associated emissions were of low relevance to an efficient operation.

Public Opinion [Figure 5-12]

Interestingly, operational carbon emissions received maximum materiality points when considering public opinion. As a result of increased public awareness and, more importantly, interest in climate change, respondents suggested that businesses report their operational carbon emissions to build a positive public perception. For what is assumed to be a similar reason, the concept of 'net-zero carbon' and the environmental impact of goods and services sold also scored highly for public opinion. Moreover, the findings showed that educating customers through the dissemination of information was another crucial factor in public opinion. An additional sub-metric that scored highly was the type of electricity procured by a business, by which the statement suggests that through procurement of low carbon and renewable energy, public opinion of a company will improve. Conversely, the cost of energy held little importance to the respondents.

Website Traffic [Figure 5-13]

It was observed that materiality points were, on average, lower when considering website traffic as a KPI. Despite that, four sub-metrics have been identified as materially necessary, scoring over 20 points. Net-zero carbon was ranked as the most vital metric to increase traffic to a company's website; similarly, operational carbon emissions and dissemination of information to customers were ranked highly. This suggests that, through the dissemination of operational carbon emissions, sustainability metrics, and net-zero goals, a company is likely to receive more visitors to its website, which in turn suggests that a business will increase its chances of gaining new customers; additionally, it is likely to improve public perception of a given company.

Customer Satisfaction & Retention [Figure 5-14 & Figure 5-15]

The KPIs' customer satisfaction' and 'customer retention', have been combined in this analysis of results as the findings are related. Taking into consideration customer satisfaction as an essential business indicator, the survey responses show that providing information to customers for educational purposes is an important metric to consider, scoring nearly full points (39). The researcher felt that dissemination of any carbon management practice within the business would positively impact customer satisfaction and retention. Further observation showed that sub-metrics relating to a company's buildings and infrastructure are vital to providing a positive customer experience. Unsurprisingly, a well-maintained, comfortable building that considers its occupants' well-being will prove popular among customers and clientele, helping to retain a substantial market share. By contrast, the quantity and frequency of goods procured were deemed to have little importance on customer satisfaction and retention.

Sales Revenue

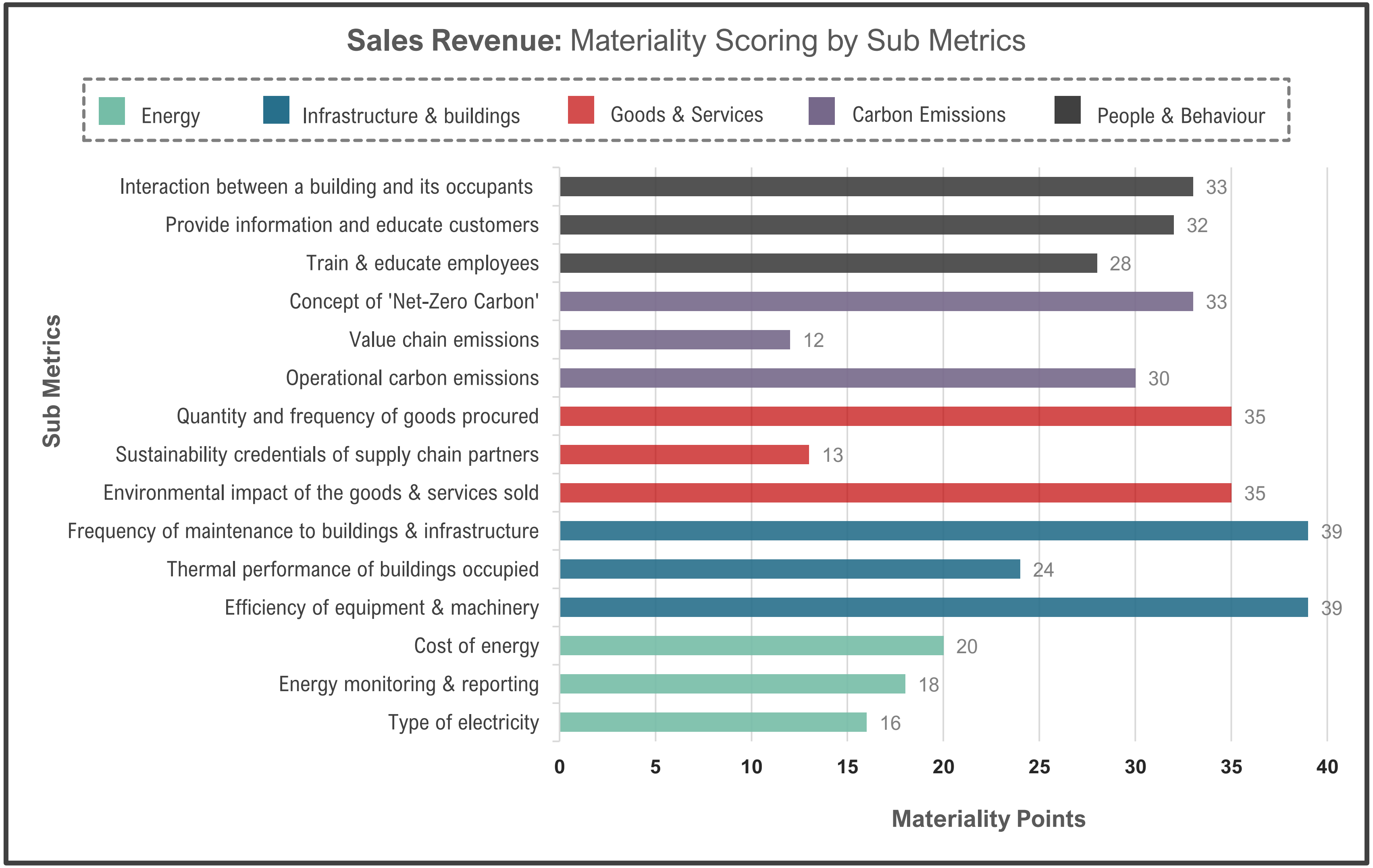


Figure 5-8. Materiality Assessment: Scoring Sub Metrics Against Sales Revenue

Net Profit

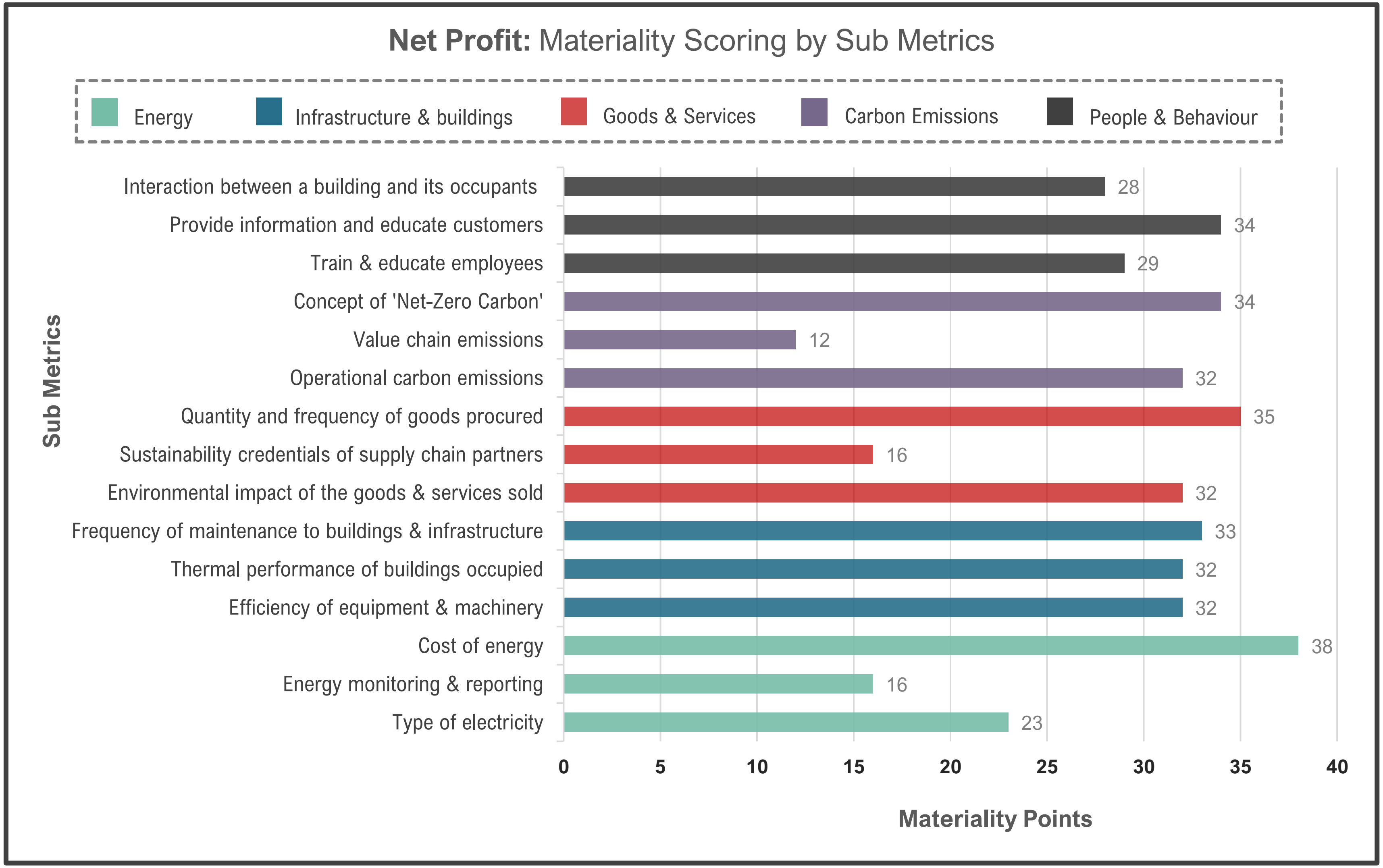


Figure 5-9. Materiality Assessment: Scoring Sub Metrics Against Net Profit

Staff Retention

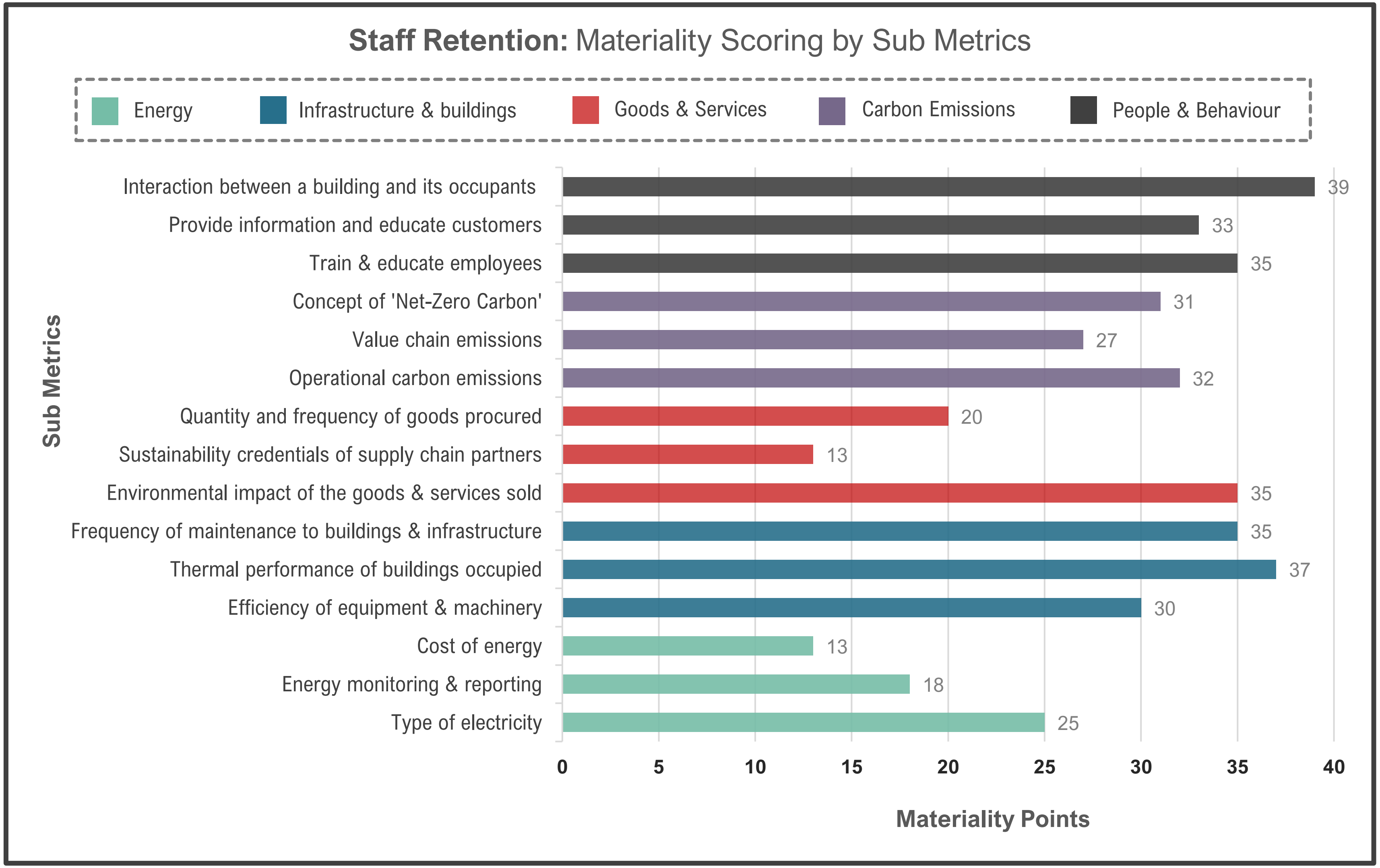


Figure 5-10. Materiality Assessment: Scoring Sub Metrics Against Staff Retention

Operational Efficiency

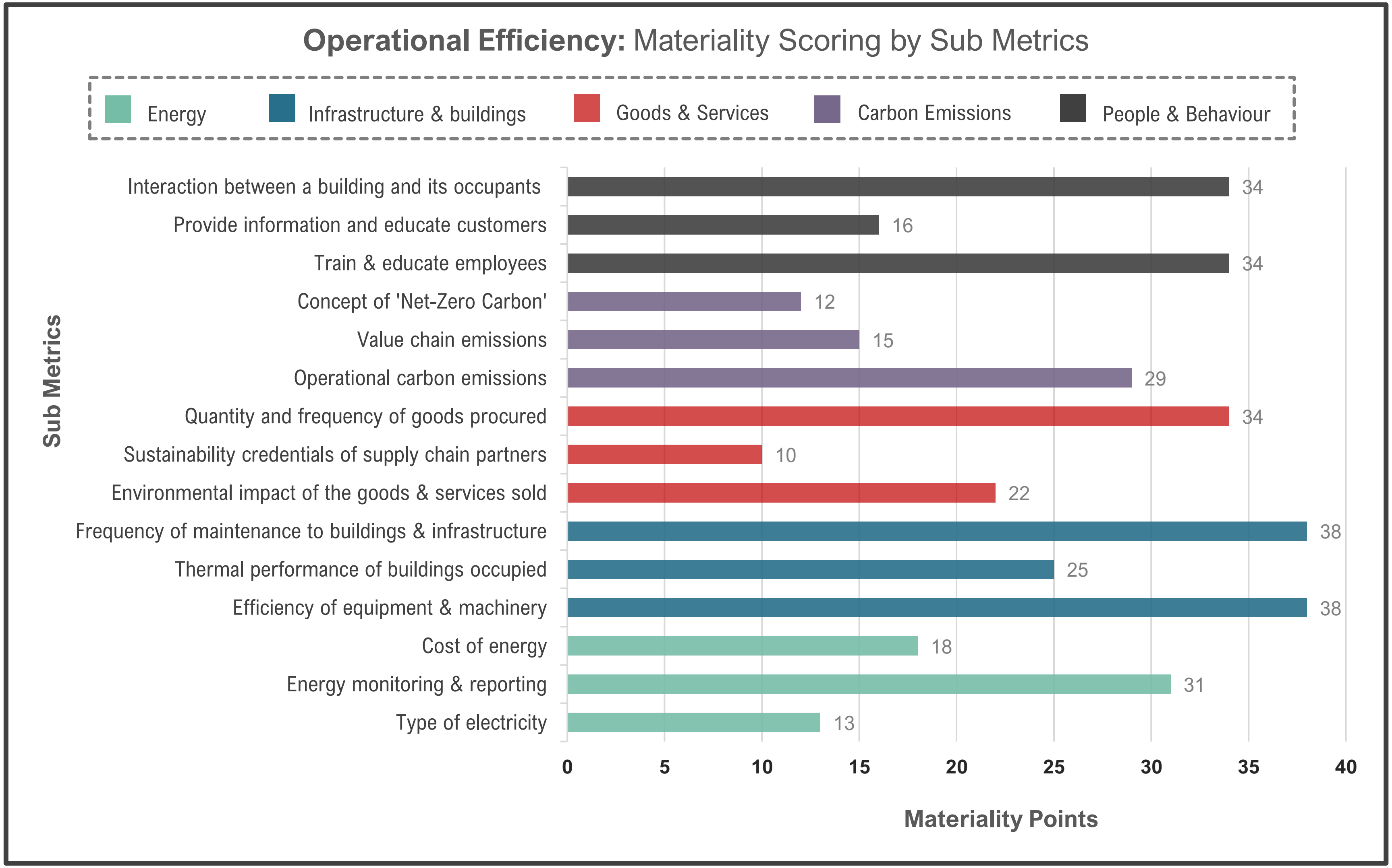


Figure 5-11. Materiality Assessment: Scoring Sub Metrics Against Operational Efficiency

Public Opinion

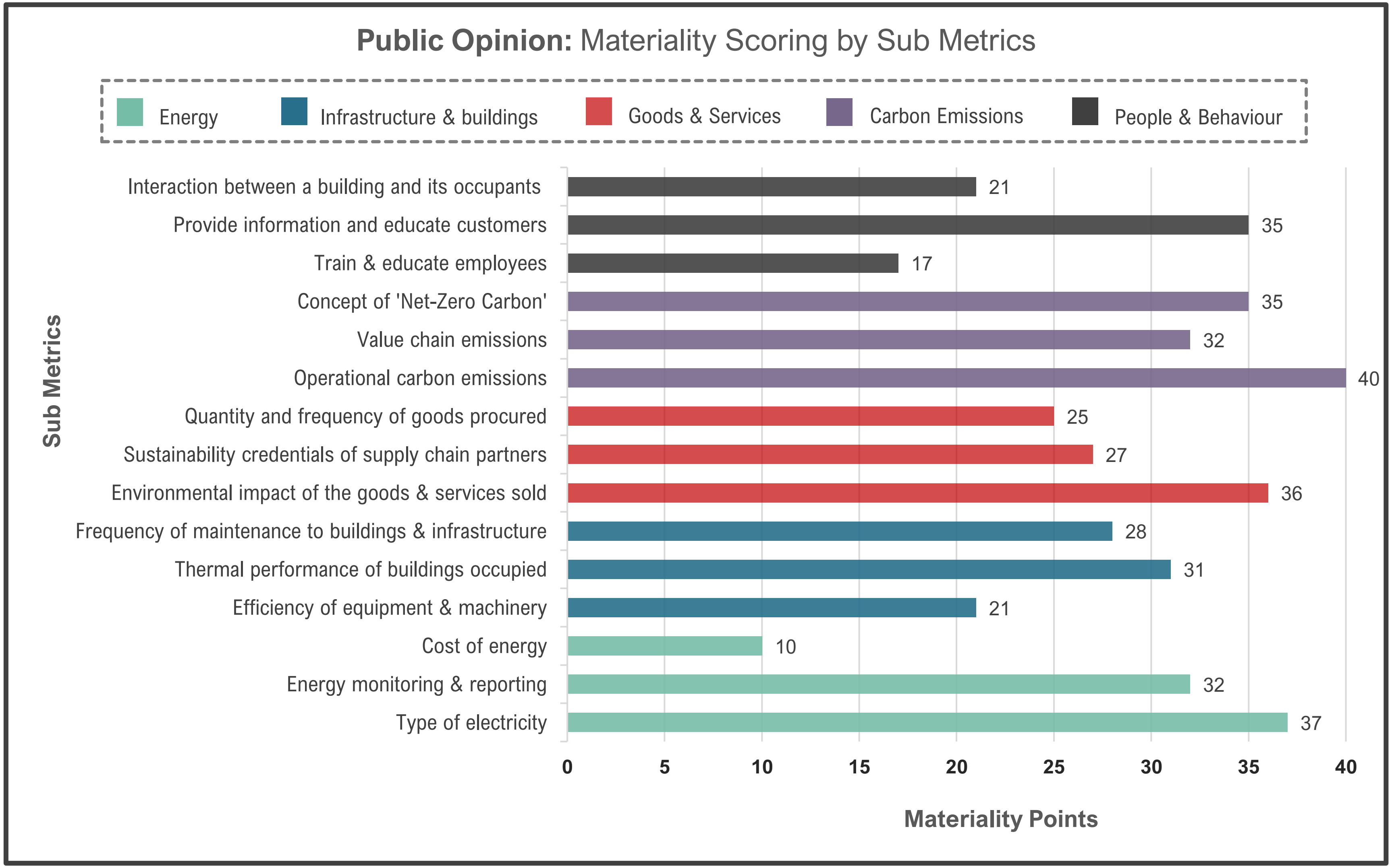


Figure 5-12. Materiality Assessment: Scoring Sub Metrics Against *Public Opinion*

Website Traffic

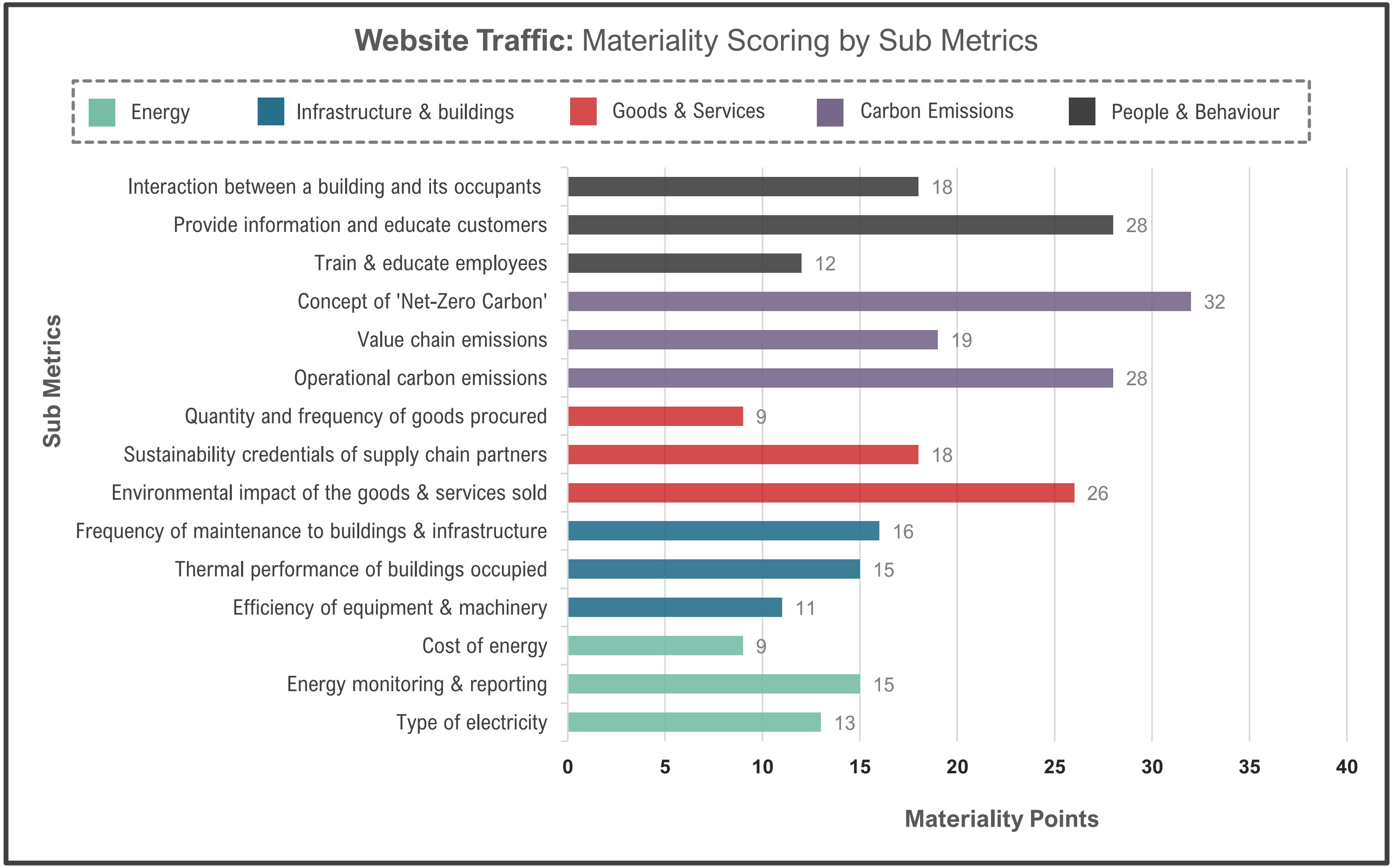


Figure 5-13. Materiality Assessment: Scoring Sub Metrics Against Website Traffic

Customer Satisfaction

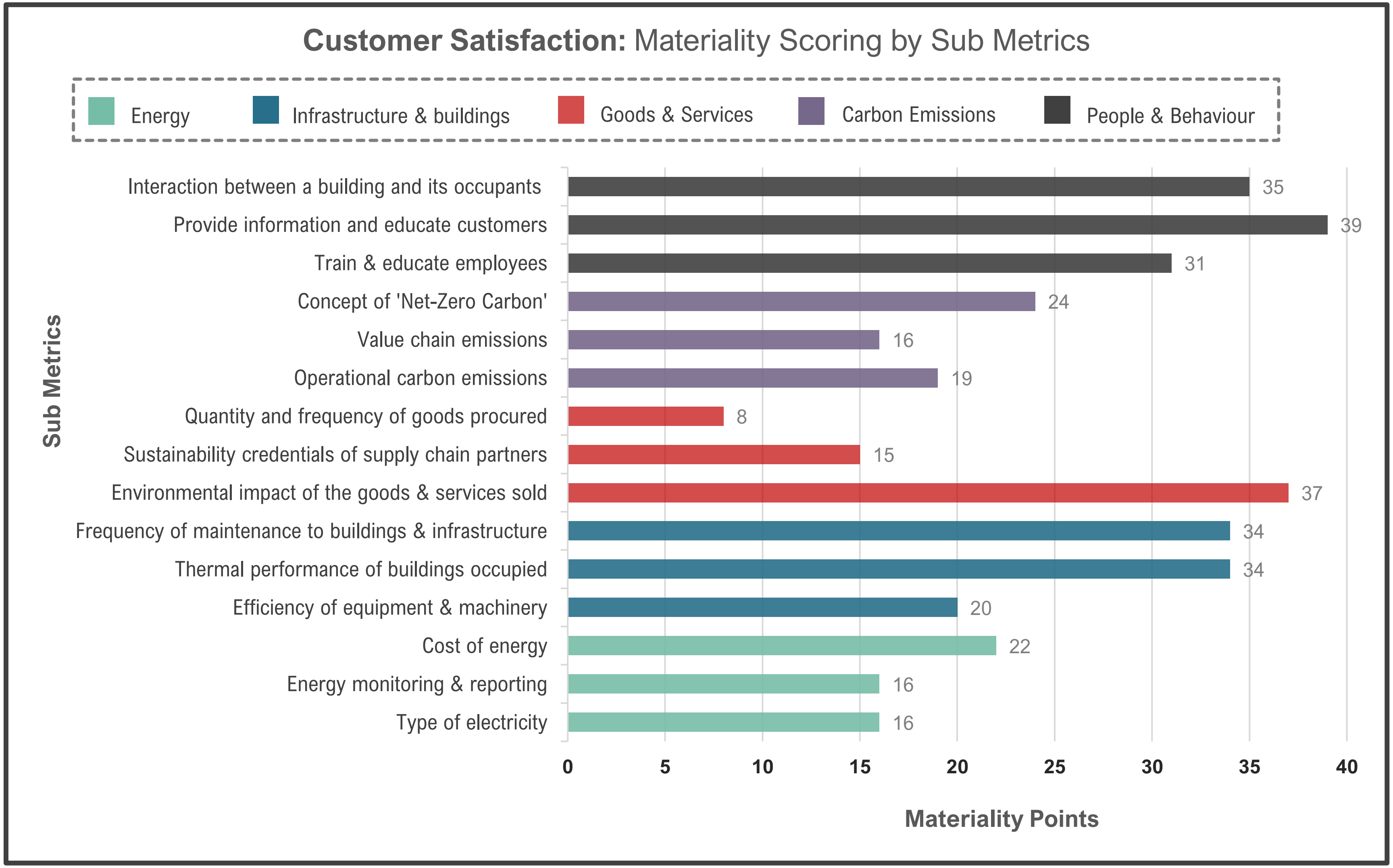


Figure 5-14. Materiality Assessment: Scoring Sub Metrics Against Customer Satisfaction

Customer Retention

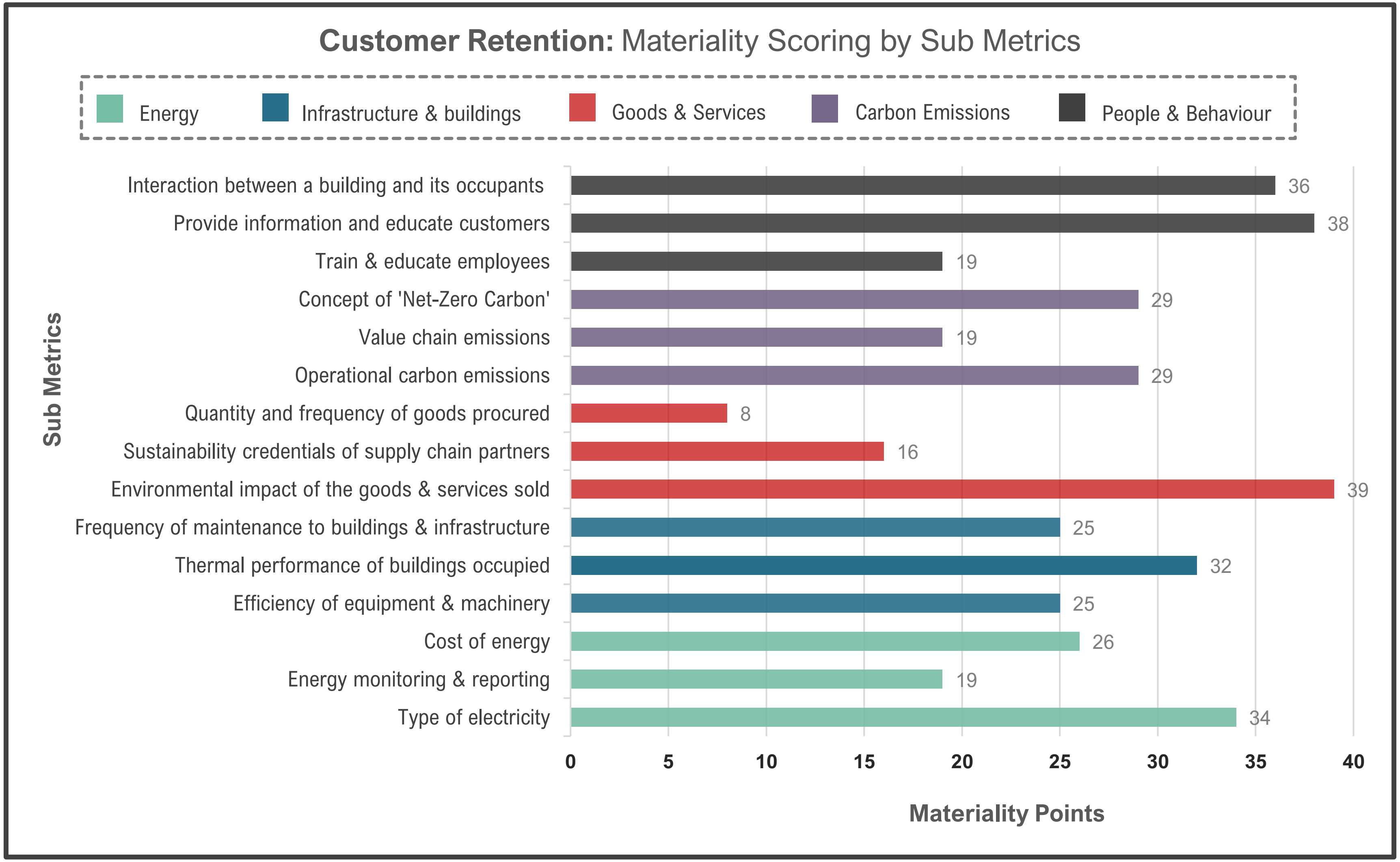


Figure 5-15. Materiality Assessment: Scoring Sub Metrics Against Customer Retention

5.3.2 Stage 2: Defining the Scope

After thoroughly evaluating and synthesising the data gathered from the materiality survey and the subsequent interpretation of these results, a critical step was identifying and prioritising the metrics that held the most significance for the selected stakeholder group. This prioritisation was instrumental in shaping the structure of the carbon management (CM) framework and its supporting tools, ensuring they align with the material concerns of the intended end-users.

5.3.2.1 Net-Zero Operational Carbon

An emerging insight considered for integration into the framework focused on net-zero carbon, particularly concerning measuring, reporting, and reducing operational emissions[1]. Throughout the materiality assessment, stakeholders frequently indicated operational emissions as a potential area of importance. Based on this preliminary feedback, it seemed prudent to prioritise operational emissions in the framework while acknowledging the complexities associated with value chain emissions[2], as identified through the preliminary investigative study (refer to Chapter 4), recognising that SMEs may often lack extensive resources and expertise in carbon management (Hendrichs and Busch, 2012b), the approach considered starting with more manageable internal emissions before exploring the broader, more complex value chain emissions.

The materiality assessment suggested that the environmental impact of goods and services sold by a business might be a significant metric. This led to a preliminary focus on how a company's operations and product offerings might affect the environment. According to the Environmental Protection Agency (EPA, 2009), environmental impact involves any change to the ecosystem, whether harmful or beneficial, resulting from a company's actions, processes, and systems. This preliminary finding highlighted the potential importance of measuring such impacts, especially concerning carbon management practices.

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[1] *Operational emissions refer to Scopes 1 and 2 as defined by the Greenhouse Gas Protocol* (WBCSD and WRI, 2004)*– refer to Section 5.3.1.2 for complete definition.*

2 *Value chain emissions refer to Scope 3 as defined by the Greenhouse Gas Protocol* (WRI and WBCSD, 2011) *– refer to Section 5.3.1.2 for complete definition.*

5.3.2.2 Buildings & Infrastructure

In 2019, the UK government established an ambitious target to bring national emissions down to net-zero by 2050 (Evans, 2019; Irfan, 2019; Levy, 2019), which demands a thorough approach to account for, reduce, and potentially offset carbon impacts stemming from buildings and infrastructure. The UK Green Building Council (UKGBC) contributed to this discourse by suggesting in their 2019 report that investing in energy efficiency and demand reduction could be a cost-effective strategy to minimise the need for new infrastructure in achieving a zero-carbon energy system (UKGBC, 2019b).

The materiality assessment tentatively identified the significance of buildings and infrastructure, focusing specifically on their operation and maintenance by companies. The assessment leads to the preliminary recommendation that when aiming to reduce operational emissions, it may be beneficial for companies to assess the current state of their buildings and infrastructure (UKGBC, 2019b). This evaluation includes reviewing thermal performance standards, as improved thermal performance could enhance energy efficiency, thereby potentially reducing energy demand and associated operational emissions. As a result, companies may need to conduct audits of their buildings and sites to measure thermal and energy efficiency before considering possible efficiency improvements and demand reduction measures.

The findings also suggest reviewing the efficiency of a company's infrastructure, including equipment and machinery. Research has shown that regular maintenance of these assets could improve energy efficiency and enhance operational efficiency (Kappatos, 2021). This, in turn, could lead to increased sales revenue and net profit while reducing carbon impact. It is also suggested that frequent equipment maintenance could be valued by staff, potentially easing their work and improving working conditions. Similarly, customer satisfaction, particularly in businesses where customers often visit the site, may also be positively impacted.

Another aspect that emerged as potentially significant is the interaction between a building and its occupants. This relationship is considered an essential factor in enhancing energy and operational efficiency (Harputlugil and de Wilde, 2021). It is thought that there is a notable performance gap in energy-efficient building designs, with actual energy use often differing from predictions (Hu *et al.*, 2020).

This discrepancy is partly attributed to insufficient consideration of occupant behaviour in building energy models (Delzendeh *et al.*, 2017). Several studies have emphasised the importance of factoring in occupant behaviour when assessing a building's energy performance (Yan *et al.*, 2015; Delzendeh *et al.*, 2017; Rinaldi, Schweiker and Iannone, 2018; Rouleau, Gosselin and Blanchet, 2019; Carlucci *et al.*, 2020). It is also suggested that the relationship between a building and its occupants could substantially impact energy performance more than the fabric efficiency of the building materials used (Rinaldi, Schweiker and Iannone, 2018).

5.3.2.3 Training & Education

The potential role of education in reducing environmental impacts has been recognised for some time, gaining initial prominence at the UN Conference on the Human Environment in Stockholm in 1972. This conference sought to establish a common perspective and principles to guide human actions in preserving and enhancing the environment. Principle 19 (of 26) highlighted the importance of environmental education for all ages as a key component in forming opinions and coordinating efforts, whether by individuals, businesses, or communities (UNEP, 1973). This principle also emphasises the potential benefit of disseminating information to increase public awareness of environmental impacts.

In the materiality assessment, stakeholders indicated that education could significantly affect both employees and customers. The practice of carbon management, particularly in a business context, is relatively new and often faces a general lack of knowledge. This barrier seems more pronounced in SMEs, as highlighted during the focus group study (refer to Chapter 4). These smaller companies may not have the resources to delve into this emerging field. Therefore, well-structured and accessible information could be crucial in fostering understanding and interest in carbon management practices among companies and their employees.

When a company decides to pursue carbon management, involving and educating employees in this transition seems essential. Adapting standard operating procedures, introducing new policies, and altering supply chains are substantial undertakings, demanding significant time and effort, especially regarding staff retraining. This challenge is often magnified in SMEs due to their limited financial and human resources. Consequently, any recommendations or actions proposed in the carbon management framework aim to be feasible for implementation without drastically impacting business operations. This cautious approach also influenced the decision to emphasise value chain (scope 3) emissions less, as addressing these emissions could require extensive changes in business practices and policies.

Beyond staff education, disseminating information to customers, clients, and site visitors appears to have less impact on operational emissions but still holds some significance for SMEs. Studies suggest customer education can bring ancillary benefits, such as increased loyalty (Suh et al., 2015; Bell, Auh, and Eisingerich, 2017), potential sales growth, and enhanced company reputation (Chan, 2021). Reflecting on these findings, the education of both employees and customers was incorporated as a critical consideration in developing the framework.

5.3.2.4 Study Aim & Objectives

As a result of the insights gained from the academic literature (as detailed in Chapter 2), the preliminary investigative focus group study (Chapter 4), and the materiality assessment (Section 5.3.1 of this chapter), the researcher set the following study aim:

To guide and educate SMEs and their customers toward achieving net-zero operational carbon emissions.

Building on this aim, three key metrics were identified from the materiality assessment to define the scope of the proposed carbon management framework: Net-Zero Operational Carbon, Buildings & Infrastructure, and Training & Education. These metrics laid the groundwork for what evolved into a framework for carbon management within SMEs. They informed and shaped the following objectives:

- *To create a systematic process for carbon management aimed at net-zero operational carbon for SMEs.*
- *Prioritising fabric and energy efficiency to minimise energy demand and associated emissions.*
- *Creating an intuitive framework that can be seamlessly integrated into a company's business model.*
- *Focusing on educating employees and customers about carbon management, alongside implementing training for changes in standard operating procedures (SOPs).*

5.4 Stage 3. Developing a Carbon Management Framework

5.4.1 The Greenhouse Gas Protocol – A Framework for Large Corporates

The key stages required to achieve net-zero operational carbon. In 2001, the World Business Council for Sustainable Development (WBCSD) and the World Resources Institute developed *The Greenhouse Gas Protocol: A Corporate Accounting and Reporting Standard*, later revised in 2004. The protocol was the first globally recognised standard to be developed for corporate business and provided a comprehensive carbon management standard that any organisation could follow. The major problem with the Greenhouse Gas Protocol (hereby referred to as the GHG Protocol) for application to SMEs is its complexity and lack of consideration for smaller businesses; most examples found in the protocol are from multinational manufacturers, energy companies, or financial institutions. As discussed previously, this makes it challenging to understand how to apply some of the processes and whether they are relevant for an SME, especially given the lack of financial and human resources. As a result, the GHG protocol was used as a basis for developing a novel systematic framework, guiding SMEs to incorporate CM into everyday business operations.

It was essential to understand the typical sources of a business's operational carbon, defined as the amount of carbon emitted during the operational or in-use phase of a building, vehicle, equipment, or machinery. The protocol classifies two categories for operational carbon, otherwise known as scopes (WBCSD and WRI, 2004), Table 5-6 defines the two scopes and provides some generic examples.

Table 5-6. Operational Carbon - Emissions ScopeS

Scope	Definition	Examples
1	Direct emissions from operations that are owned or controlled by the reporting company	Fuel or gas used in owned or controlled vehicles. Fuel or gas used for stationary combustion (e.g., boilers, furnaces, generators) Fuel or gas used in machinery (e.g., plant equipment, agricultural machinery)
2	Indirect emissions from the generation of procured electricity consumed by the reporting company	Electricity used to power buildings and infrastructure

5.4.2 A Systematic Approach

Findings from the systematic literature survey and focus group study (detailed in Chapters 2 and 4, respectively) highlighted the need for a well-structured approach to developing the carbon management framework. In this thesis, the choice of a systematic framework seems particularly appropriate, given its relevance and applicability to the project's objectives (refer to Section 5.2.1).

In contrast to other types, such as conceptual, theoretical, or policy frameworks, systematic frameworks emphasise the practical implementation of plans and strategies (Broman and Robèrt, 2017). This aligns with the pragmatic approach outlined in the research methodology (Chapter 3). Nawaz and Koç (2018) discuss using a systematic framework, offering a clear, step-by-step guide for processes, which could be crucial for managing and reducing operational carbon emissions in SMEs. The researcher believes this type of framework is potentially the most optimal for the objectives set out in this thesis for several reasons:

1. **Practicality and Implementation:** Unlike theoretical or conceptual frameworks that often focus on abstract ideas or relationships between variables, a systematic framework offers concrete steps and procedures, ensuring actionable outcomes.
2. **Operational Focus:** Given the project's aim to address operational (Scope 1 & 2) carbon impact in SMEs, a systematic framework appears to be well-aligned with operational activities (identified through the focus group study, Chapter 4), making it a potentially relevant choice for businesses seeking to implement carbon management practices.
3. **Ease of Integration:** Designed for seamless integration into existing operations, systematic frameworks align with the objective of developing a framework that enables SMEs to incorporate carbon management into their core business model with minimal disruptions.
4. **Educational and Training Elements:** Including educational and training components is a key aspect of the proposed framework. Systematic frameworks can structure these elements effectively, ensuring that employees and customers are adequately informed about carbon management practices.

5. **Scalability and Adaptability:** Systematic frameworks can be tailored to different SMEs' varying needs and scales, making them potentially flexible and adaptable to different business sizes and sectors.

In conclusion, the systematic framework design chosen for this research not only aligns with the specific needs of SMEs in managing their carbon emissions but also offers practical, implementable, and adaptable solutions. This approach differentiates it from other frameworks, which in the opinion of the researcher suggests a suitable choice for meeting the research objectives.

5.5 Version 1 - CMF-V1

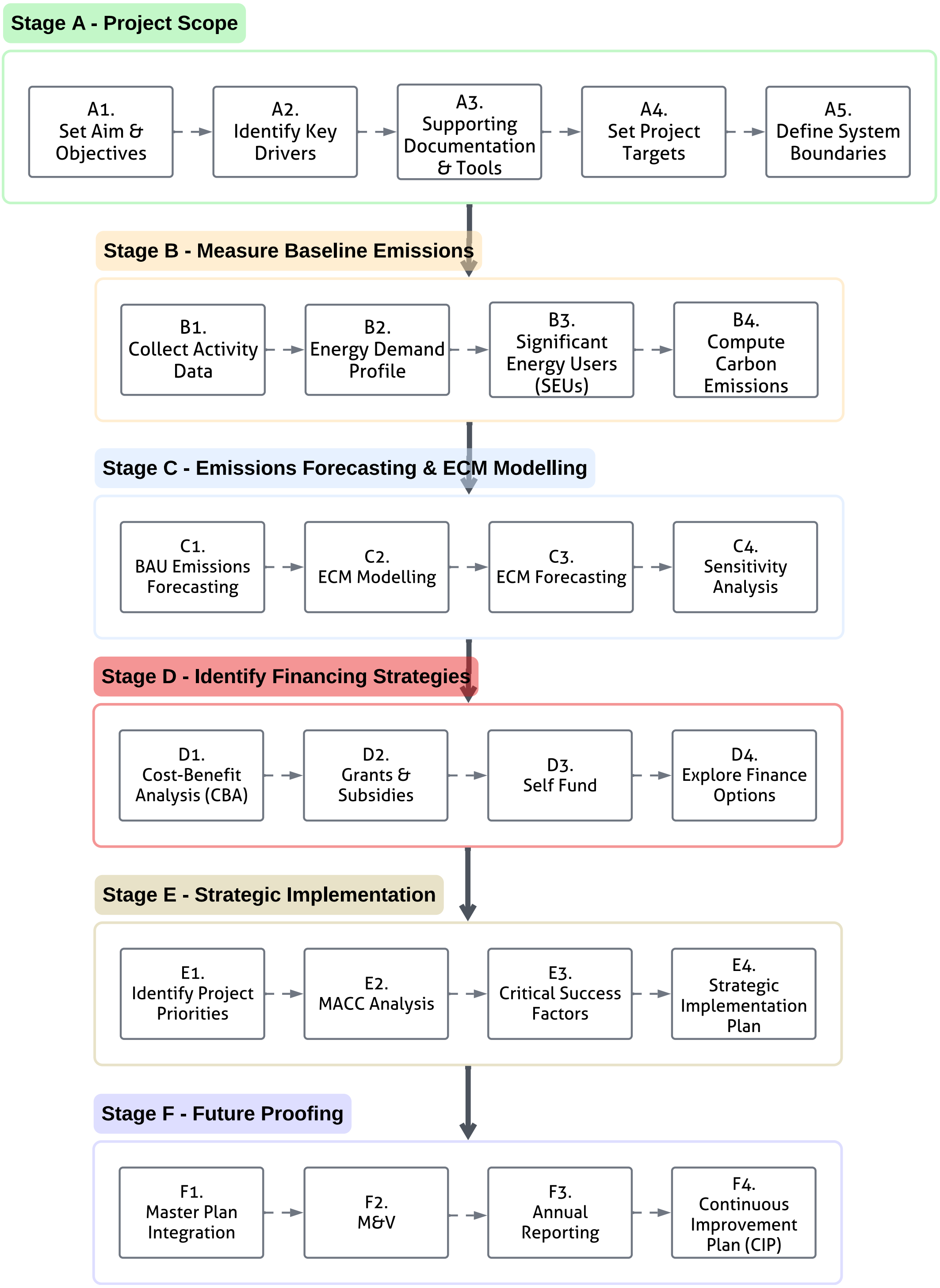

Figure 5-16. Carbon Management Framework – Version 1 (CMF - V1)

The initial iteration of the **Carbon Management Framework (CMF-V1)**, illustrated in Figure 5-16, was conceived based on insights gathered from the focus group. This design aimed to incorporate a comprehensive range of stages, providing a structured approach to carbon management. The framework comprises six stages, each informed by carbon management practices identified in the literature review (Chapter 2). The design adopts a linear and sequential flow, mirroring the format of established methodologies like The GHG Protocol (WBCSD and WRI, 2004), to ensure coherence and ease of understanding.

The first major iteration of the carbon management framework (illustrated in Figure 5-16 CMF-V1) was developed based directly on the focus group's findings. Table 5-7 provides a detailed design breakdown, including as many stages as possible for a clear and structured approach to carbon management. This first design was split into six stages of carbon management, adapted from the concepts of carbon management practices (identified in the literature survey set out in Chapter 2) and followed a linear sequential design style, with each step following from the previous. A linear design process was chosen to follow the style of previous methodologies, such as The GHG Protocol.

Table 5-7. CMF-V1 Stages and Tasks

Stages	Tasks	Description
Stage A Project Scope	A1. Set project aim & objectives	Define the overarching goals and specific objectives of the carbon management project.
	A2. Understand the key drivers	Identify and understand the primary factors motivating the business to manage its carbon footprint.
	A3. Identify supporting documentation and available tools	Gather relevant documents, such as industry guidelines, and identify tools that can assist in managing the project.
	A4. Set Project targets	Establish specific, measurable targets for carbon management to guide the project's direction and outcomes.
	A5. Define system boundaries	Determine the project's scope by defining which operations, activities, and emissions sources will be included.
Stage B Measure Baseline Emissions	B1. Collect activity data	Gather data on scope 1 & 2 activities, such as energy usage, transportation, and production processes.
	B2. Understand energy demand	Analyse the organisation's energy consumption patterns to identify areas of high energy use.
	B3. Identify significant energy users (SEUs)	Identify the parts of the organisation's processes that consume the most energy.
	B4. Compute carbon emissions	Calculate the total carbon emissions based on the collected activity data and established emission factors.

Stage C Emissions Forecasting & Energy Conservation Measure (ECM) Analysis	C1. Business-as-usual (BAU) emissions forecasting	Project future carbon emissions under a 'business as usual' scenario without additional intervention measures.
	C2. Identify feasible energy conservation measures (ECMs)	Explore potential measures that can reduce energy consumption and carbon emissions.
	C3. Model feasibility of ECMs	Assess the practicality and effectiveness of the identified ECMs.
	C4. Perform sensitivity analysis on ECM modelling	Evaluate how changes in variables affect the outcomes of ECMs to understand their robustness and potential impact.
Stage D Financing Strategies	D1. Undertake a cost benefit analysis (CBA) of potential carbon reduction solutions	Analyse the economic costs and benefits of potential carbon reduction solutions.
	D2. Identify grants and subsidies	Look for financial support options such as government grants or subsidies to offset the costs of implementing ECMs.
	D3. Self-fund where possible	Evaluate the organisation's ability to fund carbon management initiatives internally.
	D4. Explore financing options	Investigate external financing opportunities, such as loans or investor funding, to support carbon management activities.
Stage E Implementation	E1. Prioritise ECMs	Determine which energy conservation measures should be implemented first based on cost, feasibility, and impact.
	E2. Undertake marginal abatement cost curve (MACC) analysis	Analyse and compare different ECMs based on their cost-effectiveness and potential for reducing emissions.
	E3. Identify critical success factors (CSF)	Determine the key elements that will ensure the successful implementation of the carbon management plan.
	E4. Design a strategic implementation plan (SIP)	Create a detailed plan for executing the chosen ECMs and other carbon management initiatives.
Stage F Futureproofing	F1. Integrate learnings within the current business model or master plan	Incorporate insights and best practices from the carbon management process into the organisation's ongoing operations and planning.
	F2. Undertake Measurement & Verification	Regularly measure and verify the effectiveness of implemented ECMs and other carbon management actions.
	F3. Ensure annual reporting of energy & carbon emissions	Commit to regular reporting of the organisation's carbon emissions to track progress and maintain transparency.
	F4. Develop a continuous improvement plan (CIP)	Establish a plan for ongoing evaluation and enhancement of carbon management practices to ensure continuous improvement.

5.5.1 CMF-V1 Stakeholder Feedback

Following a comprehensive review with the stakeholder group (refer to section 5.3.1.1), the feedback was provided to the researcher for amendments in the framework design, summarised in Table 5-8.

Table 5-8. CMF-V1 Stakeholder Feedback

Feedback Issue	Key Points to Take Away
Too Many Complex Stages	▪ The framework was deemed too detailed, encompassing too many different stages. ▪ The number of steps may be overwhelming for SMEs without dedicated sustainability teams.
Too Resource Intensive	▪ Stages like collecting activity data, undertaking cost-benefit analyses, and conducting sensitivity analysis on ECM projections would require significant time and resources. ▪ SMEs, with their streamlined processes, may find it challenging to allocate sufficient resources to these tasks.
Technical Expertise Required	▪ Several stages in the framework, such as modelling emissions, forecasting, and undertaking marginal abatement cost curve (MACC) analysis, would require a level of technical expertise that might not be present in many SMEs. ▪ Without in-house expertise, these tasks would necessitate external consultancy, adding cost and time to a project.
Cost Implications	▪ The need for detailed data collection, analysis, and potentially hiring external experts or consultants for stages like ECM analysis and financing strategies could impose financial strains on SMEs. ▪ These costs might be prohibitive for smaller businesses operating with tight budgets.
Overemphasis on Advanced Techniques	▪ Techniques like sensitivity analysis and ECM modelling are advanced and might be more relevant for larger organisations with more complex energy and carbon management needs. ▪ SMEs typically require simpler, more straightforward methods.

In conclusion, while CMF-V1 sets a comprehensive foundation for the framework development, its complexity, potential resource intensity, technical demands, and focus on advanced techniques may present a significant challenge for medium-sized businesses. As a result, the researcher focussed on a more streamlined and intuitive version of the framework discussed in Version 2 – CMF-V2.

5.6 Version 2 – CMF-V2

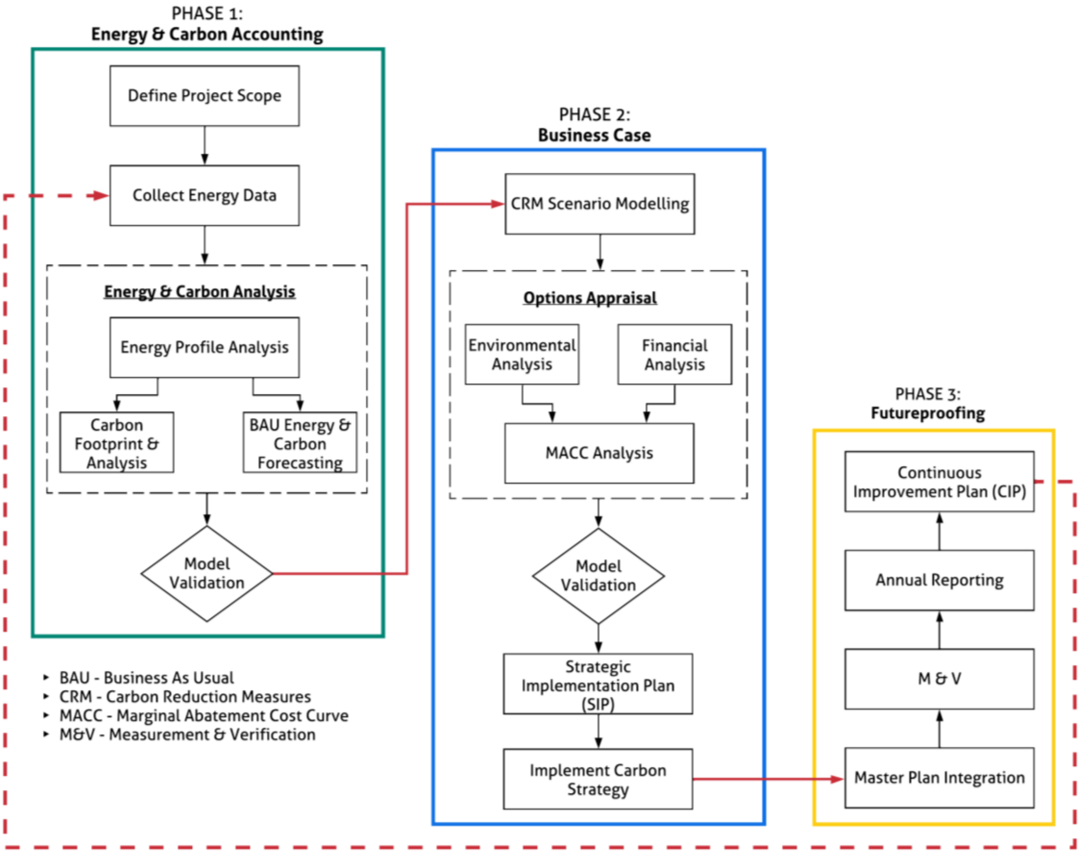

Figure 5-17. Carbon Management Framework - Version 2 (CMF-V2)

The Carbon Management Framework - Version 2 (CMF-V2), illustrated in Figure 5-17, represents an evolution from CMF-V1, aiming for greater user accessibility and clarity. The revised framework adopts a three-phase approach, which departs from CMF-V1's linear methodology, introducing a circular model that aligns with current best practices in carbon management (Mahbob and Hashim, 2022). This approach emphasises the importance of continuously reviewing and integrating carbon management practices within an organisation's business model. The three-phase simplification is intended to make the framework more accessible, especially for individuals without specialised knowledge, such as those found within medium-sized organisations, as identified in the literature (Hendrichs and Busch, 2012c; Conway, 2015b) and backed up in the findings of the focus group study (refer to Section 4.6). The three phases of the model are briefly described:

5.6.1 Phase 1: Energy & Carbon Accounting

This phase establishes a baseline, which is crucial for tracking progress (WBCSD and WRI, 2004; ISO, 2019a). It includes defining the project scope, collecting energy data, analysing the energy profile, and calculating carbon emissions. This phase focused primarily on guiding a business to measure and account for its operational emissions, setting it up for the second phase.

5.6.2 Phase 2: Business Case

The business case was designed to support the organisation in reducing its emissions, suggesting the creation of a carbon reduction measure scenario assessment. This assessment guides the user to an options appraisal of measures involving an environmental and financial analysis, providing the necessary information to undertake a marginal abatement cost curve analysis (discussed in more detail in Section 5.7) for potential carbon reduction measures.

5.6.3 Phase 3: Futureproofing

The final phase focuses on the concept of circularity within the framework, guiding users on integrating the steps taken during phases one and two into the organisation's business model. The CMF-V2 framework aims to highlight this circularity within its design by emphasising practices such as annual reporting and developing a continuous improvement plan (CIP).

5.6.4 Stakeholder Feedback – CMF-V2

CMF-V2 was again presented to the key stakeholders for criticism and review. This time, the stakeholders agreed that the design was much easier to read and, more importantly, the steps easier to follow, especially given that the framework had now been broken down into three phases. Despite the improvement in overall design, the stakeholders suggested there was still an air of ambiguity within the framework, and several questions were asked about what was required for each task. Following several productive review discussions, numerous suggestions were made for improvement, which were concluded into four key recommendations, outlined in Table 5-9.

Table 5-9. CMF-V2 Stakeholder Feedback

Feedback Issue	Key Points to Take Away
Clarity of individual tasks and lack of guidance	- Each phase and task should be defined with clear, actionable instructions. - Includes specifying the expected outcomes and providing examples or templates.
Inclusion of milestones	- Introducing milestones would give users specific targets to achieve within each phase.
Supporting Tools	- Develop or signpost tools or instruments that could assist users in completing tasks, such as carbon calculators, templates for data collection, and guides for performing analyses.
Alternative Pathways	- For tasks that are not critical, offer alternative approaches to save time or resources. - Ensures the framework remains flexible and adaptable to organisational needs and capacities.

In conclusion, CMF-V2 was a more refined and user-friendly framework than CMF-V1, particularly for SMEs who typically do not have specialised knowledge in carbon management. The feedback from stakeholders indicated that while the structure had improved, further amendments were required to ensure clarity and usability.

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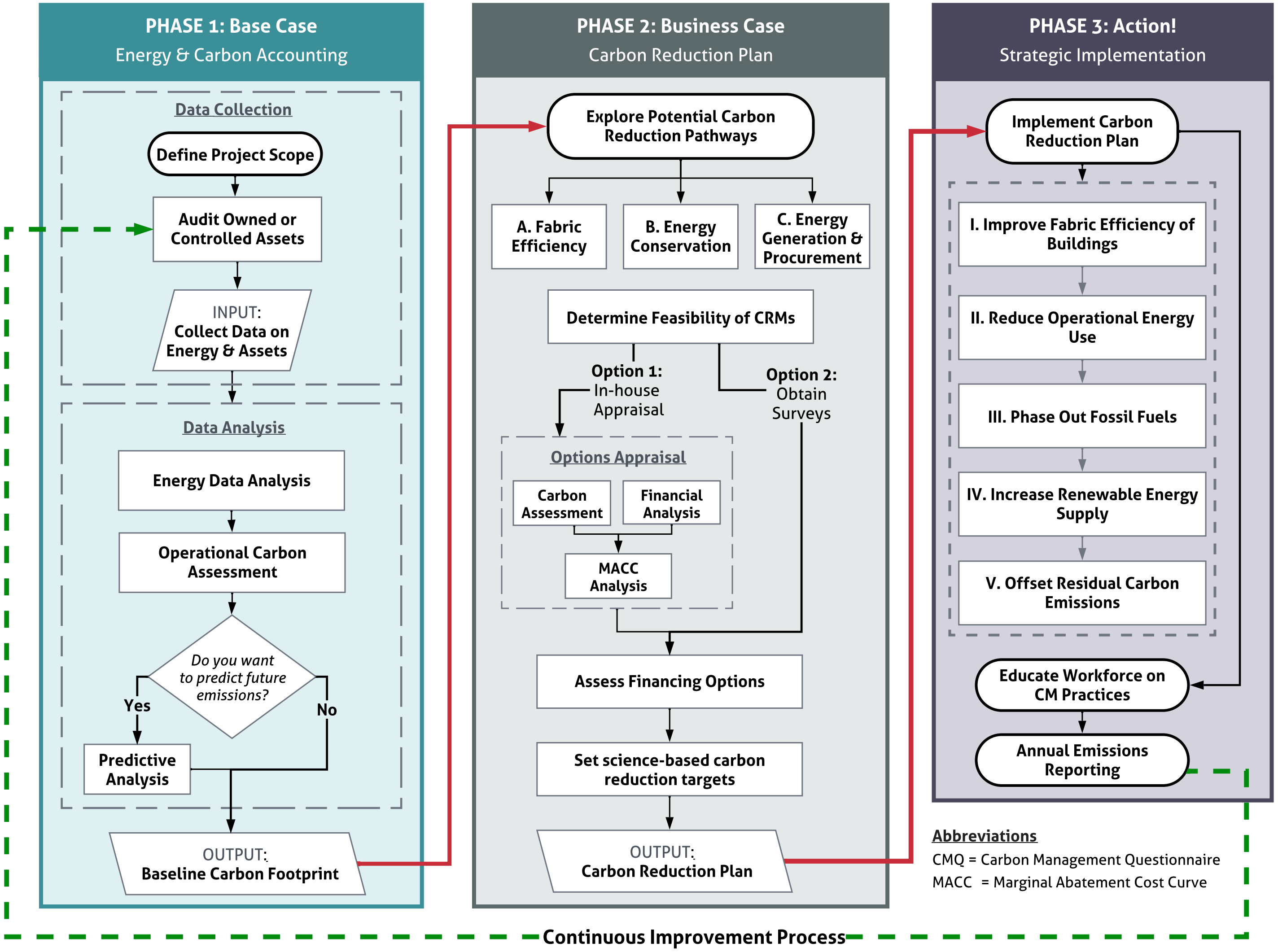
5.7 Version 3 – CMF-V3



Abbreviations
CMQ = Carbon Management Questionnaire
MACC = Marginal Abatement Cost Curve

Figure 5-18. Carbon Management Framework - Version 3 (CMF-V3)

CMF-V3 was developed in collaboration with industry experts, academics and key project stakeholders who provided critical insights, ensuring the framework's alignment with practical, real-world applications. This collaborative effort reinforces the framework's relevance and effectiveness for medium-sized enterprises in the UK.

CMF-V3 represents the culmination of iterative refinements from the framework development process, integrating stakeholder recommendations to enhance the framework's applicability through each version. This final iteration retains the structured three-phase approach defined in CMF-V2 and is designed to guide users[1] through the intricacies of carbon management (CM). The three phases were refined further from CMF-V2 to provide better descriptions with more clarity, and the naming for the phases was changed to:

Phase 1. Base Case – Energy & Carbon Accounting

Phase 2. Business Case – A Carbon Reduction Plan

Phase 3. Action! – Strategic Implementation

5.7.1 Phase 1: Base Case – Energy & Carbon Accounting

Phase 1 set out to establish a baseline for the framework user, helping them to get to grips with the concepts of CM and understanding the process required to collect and analyse data to quantify their operational carbon footprint. This initial base case provides users with the required tools to set the project scope and understand their business goals and drivers; it then proceeds to encourage the user to audit owned or occupied buildings and infrastructure. The fundamental changes to this phase are detailed in Table 5-10.

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[1] *Primarily UK medium-sized organisations*

Table 5-10. Significant Changes in CMF-V3 - Phase 1

Key Change	**Description**	**Justification**
Introduction of Site Audit and Questionnaire	- Integration of a structured site audit, which utilises a detailed questionnaire (discussed in Section 5.8.1) to facilitate data collection for the carbon assessment.	Offers a streamlined approach to understanding and documenting the current state of energy usage and building efficiency.
Streamlining Data Analysis	- Refines the data analysis process by directing the focus onto energy demand and carbon emissions, thus streamlining the user experience. - Framework evolved to make the previously mandatory forecasting step optional, allowing users to concentrate on data analysis and carbon assessment.	Modification respects users' diverse needs and capabilities, particularly those who may not require detailed forecasting for their operations.
Removal of Model Validation	- Omission of the "model validation" step	Stakeholder feedback indicated that this step could introduce complexity and potentially confuse users.
Key Output Defined	- Phase 1 now concludes with a clear deliverable: ***Baseline Carbon Footprint.***	Change enhances the framework's usability by providing a definitive endpoint to the initial phase, ensuring users have a concrete outcome upon which to build subsequent phases.
Enhanced Clarity and User Guidance	- Prioritises clarity and guidance. - Refines the process and focuses on energy and carbon accounting essentials.	To ensure a solid foundation for organisations to measure and understand their carbon footprint accurately.

5.7.1.1 Data Collection

The audit process is supported by introducing a new tool, helping the user follow a predetermined review process of their operations. The audit supporting tool was designed as a questionnaire survey (CMQ), guiding users to determine the existing state of their buildings and infrastructure in relation to energy and fabric efficiency. Moreover, the survey encouraged an audit of any vehicles, machinery, or equipment to assess fuel usage, age of assets, and recorded maintenance and service history. Further details of the carbon management questionnaire survey, or audit tool, are discussed in *Appendix D1*.

5.7.1.2 Data Analysis

Following a site audit, users are then guided to collect energy data to quantify scopes 1 and 2 carbon emissions. A further supporting tool was developed as a statistical analysis model (CM-SAM) built on Microsoft Excel to support users in data collection and analysis. Firstly, justifications for creating the tool using this software program originated from the focus group study (Chapter 4), where participants discussed using Excel to collect and store data related to business operations, including financing accounts, energy consumption data, human resources data, and more. In addition, it was observed that most companies use or have access to Microsoft Excel and understand how to use the software.

5.7.1.3 Evaluation of Carbon Accounting Tools

The landscape for carbon accounting tools has evolved significantly in recent years[2], with the emergence of various online carbon calculators offering user-friendly interfaces (Salo, Mattinen-Yuryev and Nissinen, 2019; Barendregt, Biørn-Hansen and Andersson, 2020), the uniqueness of the CM-SAM within the field has diminished, particularly for SMEs which are now well-catered to by these new tools.

While CM-SAM played a pivotal role in a field study to validate the Carbon Management Framework's (CMF-V3) methodology, as detailed in Section 6.4, its detailed discussion has been excluded from the core narrative of this thesis. The CM-SAM is documented in Appendix D2 for reference to the reader but is no longer critical to the framework's efficacy due to the availability of alternative tools that users may employ.

Some notable examples of these carbon account tools include the World Wildlife Fund's climate calculator (World Wildlife Fund, 2023) and the United Nations personal carbon footprint calculator (United Nations, 2023b). In addition, specific calculators have been developed for SMEs such as the Carbon Trust's SME Carbon Footprint Calculator (The Carbon Trust, 2023) and a similar tool from the SME Climate Hub (SME Climate HUB, 2023), both offer cost-free access, enhancing their accessibility and adoption among SMEs.

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[2] *Recent years in the thesis refer to 2019-2023.*

5.7.1.4 Phase 1 Summary

In summary, Phase 1 aims to equip the user with the necessary steps and methodologies to compute their baseline carbon footprint, setting the stage for a targeted carbon reduction plan. It emphasises the importance of adaptability in tool selection, allowing users to leverage the most current and adequate resources in their journey towards measuring and reducing their carbon impacts, with some of the significant changes detailed in Table 5-10.

5.7.2 Phase 2: Business Case – A Carbon Reduction Plan

Phase 2 of the Carbon Management Framework Version 3 (CMF-V3) builds upon the initial data assessment process, directing users to develop a strategic business case for improving energy efficiency and reducing carbon emissions. The objective of this phase guides users to formulate a comprehensive carbon reduction plan, laying out the necessary steps to transition toward reducing scope 1 and 2 emissions. The key changes to this phase are detailed in Table 5-11.

Table 5-11. Significant Changes in CMF-V3 - Phase 2

Key Change	**Description**	**Justification**
Introduction of Carbon Reduction Pathways	- Pathways serve as a guided approach for users to pinpoint appropriate carbon reduction measures.	Enables users to navigate the complexities of carbon reduction with greater ease.
Multiple Options for CRM Feasibility	- Divergence of feasibility assessments into two distinct avenues: - Option 1: In-house appraisal - Option 2: External feasibility surveys.	Provides users with the flexibility to choose the most suitable assessment method for their needs and resources, enhancing the framework's applicability.
Removal of Model Validation	- Omission of the "model validation" step	Found to be unnecessary and potentially confusing for users. Highlights commitment to user-friendliness and practicality.
Key output defined	- Phase 2 now concludes with a clear deliverable: ***Carbon Reduction Plan***	Represents the primary output of Phase 2. Ensures a solid strategy is defined for users to proceed to Phase 3 to implement carbon reduction initiatives strategically.

Enhanced Clarity and User Guidance	- Prioritises clarity and guidance. - Facilitates a more intuitive journey for users seeking to reduce their carbon footprint.	By offering clearer pathways, flexible feasibility options, and a focus on financial strategy, CMF-V3 prepares the user for effective and strategic carbon management practices.

5.7.2.1 Strategic Carbon Reduction Pathways

The process requires the user first to explore the potential avenues of carbon reduction, of which three primary pathways are suggested:

1. **Fabric Efficiency:** This first pathway prioritises a fabric-first approach as the energy performance of a building's envelope. Addressing fabric efficiency is crucial because inadequate insulation or building design can lead to excessive energy consumption for temperature regulation, thereby increasing operational emissions (Ling-Chin *et al.*, 2019; Alabid, Bennadji and Seddiki, 2022).
2. **Energy Conservation:** The second pathway optimises energy consumption across a company's operations. Enhancing the energy efficiency of assets such as buildings, infrastructure, vehicles, and machinery reduces energy demand and, consequently, a lower carbon footprint (Eyre and Killip, 2019; Barret *et al.*, 2021). This pathway curbs emissions and can yield significant financial savings and boost profitability through reduced energy expenditures.
3. **Energy Generation and Procurement**: The third pathway targets the source of energy used and promotes the transition from fossil fuel reliance to renewable energy sources where possible. Businesses are urged to explore on-site and off-site renewable energy generation and procurement strategies aligning with their operational demands.

5.7.2.2 Carbon Reduction Measure (CRM) Feasibility

Following on from the exploration of *carbon reduction pathways*, the framework (CMF-V3) guides users to identify suitable and applicable carbon reduction measures (CRMs). Upon identification of suitable CRMs, the user is then led to choose whether to undertake a detailed analysis of the measures or move to the next step. This option will depend on the user's requirements, knowledge of a particular measure, available resources, and whether any external support is provided.

For those opting for a detailed analysis, the framework recommends an 'options appraisal' through external feasibility surveys or an internal assessment to evaluate both the carbon reduction potential and the financial implications of the CRMs.

Combining the results of the carbon and financial assessment allows the user to create a marginal abatement cost curve (MACC), a valuable tool used to illustrate the economics associated with carbon mitigation. Policymakers extensively use the tool for various environmental issues, which is increasingly used to aid decision-making to determine climate policy. A MAC curve presents the carbon abatement (or reduction) scenarios relative to a business-as-usual pathway, which are then broken into discrete 'blocks', with each block representing an individual or set of carbon reduction measures (Tempest, 2016; Vogt-Schilb, 2018).

5.7.2.3 Science-based Targets Setting

Subsequently, the framework guides users in setting science-based carbon reduction targets[3] that align with the global objective to limit global temperature rise below 2°C, as stipulated by the Paris Agreement (UNFCCC, 2015). These targets introduce a structured ambition to the carbon reduction plan (CRP), ensuring the organisation's strategies are grounded in scientific rationale and temporal benchmarks.

5.7.2.4 Creating a Carbon Reduction Plan

Once pathways have been explored, potential measures identified and reviewed for feasibility, and targets are set, the user can begin developing a carbon reduction plan. This aims to ensure that the carbon reduction plan is strategically sound, embedded in the company's operational ethos, and supported at the highest levels of governance.

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[3] *Carbon reduction targets are science-based if they align with the level of decarbonisation required to keep global temperature increase below 2°C relative to pre-industrial levels (CDP et al., 2017; The Carbon Trust, 2018).*

5.7.2.5 Phase 2 Summary

Phase 2 of CMF-V3 is pivotal, as it transitions businesses from awareness and assessment to active planning and target setting. It adopts a holistic view of carbon management that aims to exceed operational boundaries, embedding carbon management at the core of business strategy.

5.7.3 Phase 3: Action! – Strategic Implementation

The third and final phase of the Carbon Management Framework Version 3 (CMF-V3) indicates the critical transition from planning to execution of the Carbon Reduction Plan (CRP), formulated in Phase 2. The significant changes to this phase are detailed in Table 5-12.

This phase is designed to be pragmatic and action-oriented, emphasising two parallel processes:

a) **Strategic Implementation of Carbon Reduction Plan (CRP)** – Supports the user to implement the strategy set out in the CRP.

b) Educate Workforce on the Practices of Carbon Management – Disseminating carbon management knowledge throughout the organisation to embed carbon management practices across all levels of operation.

Table 5-12. Significant Changes in CMF-V3 - Phase 3

Key Change	Description	Justification
Refinement and Restructure	- Critical changes in the structure and operational focus. - Renamed from "futureproofing" to "Action! Strategic Implementation"	Aims to instil a sense of urgency and commitment towards executing the CRP.
Simplification and Clarity	- Removal of the following steps from CMF-V2: - Integration into the master plan - Measurement & verification - Continuous improvement plan.	These steps were found to introduce complexity and confusion. Streamlines the approach to concentrate on guiding users in practically implementing their carbon reduction strategies.
Implementation Hierarchy	- Introduces an implementation hierarchy, serving as a guideline to industry best practices in carbon management.	Assists users in prioritising and systematically enacting the necessary changes and measures identified in the CRP.

Workforce Education	- Introduces a new step in educating the workforce.	Crucial as it ensures that the principles of carbon management are understood and embraced across all levels of the organisation. Facilitating a more holistic and effective implementation.
Closes with Annual Emissions Reporting	- Finishes the phase with annual emissions reporting. - Encourages circular reporting process.	Serves as a crucial feedback mechanism. This reporting assesses the effectiveness of the implemented measures and resets the focus back to Phase 1, thereby creating a continuous cycle of improvement and reassessment.

5.7.3.1 A Carbon Reduction Hierarchy

The strategic implementation phase advocates a 'reduction first' approach, as recommended by the UK Green Building Council's (UKGBC) Net-Zero Carbon Buildings Framework, recreated in Figure 5-19 (UKGBC, 2019b). This methodology prioritises minimising energy demand and fossil fuel reliance upfront rather than relying on carbon offsets as a primary solution. Such an approach reflects a commitment to environmental stewardship and demonstrates a proactive change in business operations.

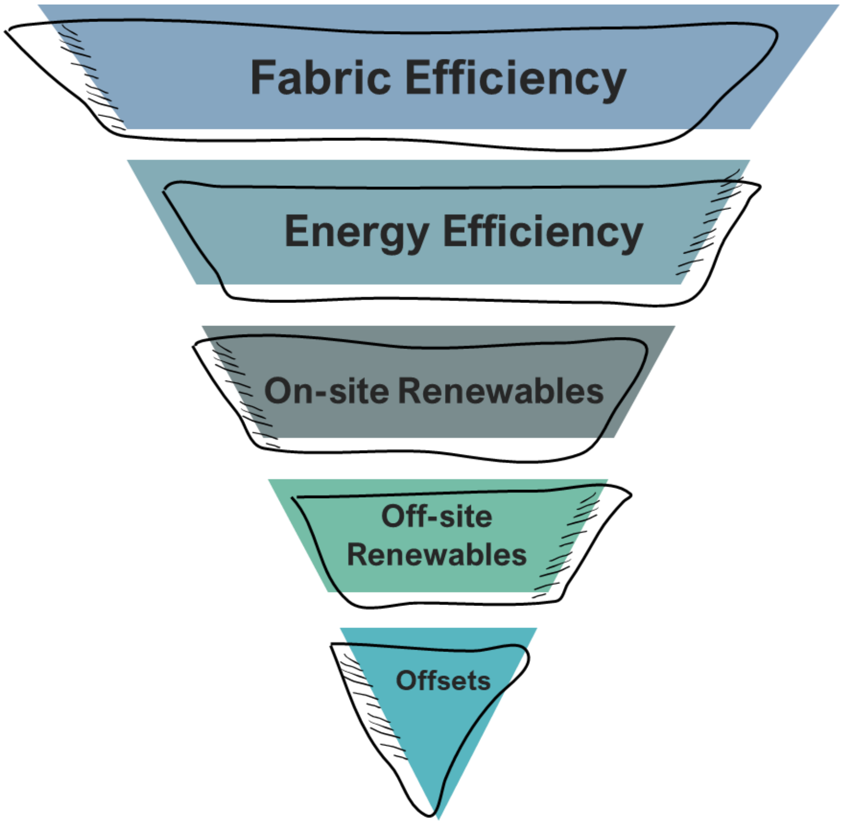

Figure 5-19. Carbon Reduction Hierarchy - Adapted from UKGBC (UKGBC, 2019c)

5.7.3.2 Systematic Implementation Steps

The implementation process outlined in phase 3 of the carbon management framework (refer to CMF-V3 in Figure 5-18) is systematic, guiding users through a sequence of strategic actions:

I. **Improve Fabric Efficiency of Buildings:** Where applicable, undertake improvements in the building envelope at company site(s) to improve overall energy efficiency.

II. **Reduce Operational Energy Consumption:** Reducing energy usage through increased efficiency in systems and equipment operation.

III. **Phase Out Fossil Fuels**: Reducing the use of fossil fuels and moving to low-carbon and sustainable energy sources such as electricity and sustainable fuels (e.g., Hydrotreated Vegetable Oil – HVO (Aatola *et al.*, 2009)).

IV. **Increase Renewable Energy Supply:** Prioritising on-site renewable energy generation to encourage energy decentralisation and reliance on the national grid, with off-site renewables and power purchase agreements as secondary options.

V. **Offsetting Residual Emissions:** Investing in high-quality carbon credits to offset any remaining emissions, adhering to the *'Oxford Principles for Net Zero Aligned Carbon Offsetting'* (Allen *et al.*, 2020).

5.7.3.3 Continuous Improvement

The framework emphasises the importance of annual emissions reporting to establish a feedback loop for continuous improvement. By incorporating circularity into the framework, the researcher believes that eventually, the practices taught throughout the process will help to cement carbon management within the core principles of any organisation. By embedding carbon management practices within the culture, organisations will begin to gain a competitive advantage over rivals; they will be able to confidently educate the workforce, which should naturally encourage the education of customers, clients, or site visitors. This education will not only positively impact a company's image but will extend to the lives of the people and stakeholders involved who value the company.

5.7.3.4 Phase 3 Summary

Phase 3 of CMF-V3 not only prompts actionable steps towards reducing emissions but also aims to cultivate a sustainable mindset within the organisation. By integrating the practices set out, companies are positioned to lead by example, educating their workforce and influencing their wider community, ultimately contributing to the collective effort against climate change.

5.8 Supporting Tools for the Industrial Partner

This section briefly discusses the supporting instrumentation developed during the process of creating the proposed carbon management framework (CMF-V3 illustrated in Figure 5-18). Addressing a key recommendation from research stakeholders during the framework development phase (see Table 5-9), these instruments were designed to aid users in managing complex tasks, such as data collection and analysis. This need was also echoed in focus group discussions, highlighting the demand for tools to integrate and display energy and carbon data within existing key performance indicators, elaborated in Section 4.5.

5.8.1 Collaboration and Practical Application

As discussed in Chapter 3, this research was a collaboration between the University of Liverpool and Knowsley Safari (industrial partner). Knowsley Safari's involvement was instrumental, providing partial funding and a real-world setting crucial for the overarching case study design (discussed in Chapter 3). Their contribution was pivotal in achieving Objective 5 of the study (defined in Section 5.2.1): ***applying research findings and outputs to a practical, real-world case study***. Through this partnership, Knowsley Safari played a significant role in the focus group study and the framework's development, as detailed in Chapters 4 and 5.

5.8.2 Development and Role of Supporting Tools

During the framework's development phase, it became evident that additional tools were necessary to support the industrial partner's goal of reducing operational carbon emissions while enhancing the testing and validation process, as detailed in Chapter 6. This realisation led to the development of two supporting tools:

- **Carbon Management Questionnaire [CMQ]** – a carbon management screening survey to support the auditing and data collection process of a company’s operations, help define building parameters, and improve understanding of what should be accounted for when performing an operational carbon assessment.
- **Carbon management – Statistical Analysis Model [CM-SAM]** – a data analysis tool for assessing a company’s operational carbon emissions, with additional features to run a carbon and financial analysis of carbon reduction measures.

It is essential to clarify that these tools, while valuable for the practical application of the framework, particularly in the case study with Knowsley Safari, are not the primary outputs of this research. The focus of this chapter, and indeed the research, is on the novel development of a framework as a significant contribution to academic research in carbon management. While the CMQ and CM-SAM are referenced in the development phase (see Section 5.7), their role is supportive rather than foundational to the framework's success.

Acknowledging their supportive nature, these instruments are not central to the main thesis; however, they are detailed in Appendix D. This inclusion provides interested readers with comprehensive context and understanding of the tools, explaining their application in a real-world setting and their contribution to achieving operational carbon emission reduction for Knowsley Safari.

5.9 Chapter Summary

This chapter summarises a comprehensive overview of the journey taken in developing the novel carbon management framework. It offers valuable perspectives on the reasoning, difficulties, and strategic choices encountered that aim to be academically credible and practically applicable in the field of carbon management.

To aid with development, a materiality assessment was conducted to determine the importance and relevance of certain CM practices, through which a stakeholder group was established to provide crucial feedback throughout the process. The stakeholders were a combination of academic researchers from the University of Liverpool and employees from the industrial partner Knowsley Safari. This allowed for a combination of academic and industry expertise, helping to bolster the robustness of the novel framework. The materiality assessment identified three key metrics for the development stage: Net-Zero Operational Carbon, Buildings and Infrastructure, and Training and Education. These metrics defined the scope of the novel CM framework and helped to establish the primary aim and objectives:

> ***Primary Aim:*** *To guide and educate SMEs and their customers toward achieving net-zero operational carbon emissions.*
>
> ***Objectives***
>
> - *To create a systematic process for carbon management aimed at net-zero operational carbon for SMEs.*
> - *Prioritising fabric and energy efficiency to minimise energy demand and associated emissions.*
> - *Creating an intuitive framework that can be seamlessly integrated into a company's business model.*
> - *Focusing on educating employees and customers about carbon management, alongside implementing training for changes in standard operating procedures (SOPs)*

Knowsley Safari's involvement offered invaluable insights into similar-sized entities' specific needs and challenges and provided a tangible context for applying the research findings.

The development of the framework was iterative, taking onboard stakeholder feedback and peer-review insights. This process ensured that the framework developed was user-friendly and met the needs of the intended end-users, enhancing the practical application.

5.9.1 Evolution of the Framework

Version 1 (CMF-V1): Featured six stages with a linear and sequential flow, taking cues from established methodologies like The GHG Protocol.

Version 2 (CMF-V2): Evolved into a three-phase, circular model, focusing on enhancing user accessibility and clarity.

Version 3 (CMF-V3): Introduced further refinements, emphasising the transition from planning to execution and simplifying numerous elements of those proposed in previous iterations.

CMF-V3 became the final iteration of the framework ready for testing on a real-world case study. This version emphasised a measure, plan, and reduce approach through the three phases and highlighted the importance of annual emissions reporting and continuous improvement.

In conclusion, this development journey reflects a comprehensive effort to establish a practical, accessible, and effective carbon management framework tailored for medium-sized UK businesses. The systematic approach, stakeholder engagement, and iterative development of instruments highlight the framework's commitment to bridging the gap between theoretical research and practical application in the field of carbon management, retaining the pragmatic, action-focused approach defined in Chapter 3.

CHAPTER 6

6. Framework Testing & Validation: A case study of a UK safari park

6.1 Chapter Overview

The following chapter outlines the testing and validation approach for the carbon management framework developed in the previous chapter. A case study was designed and run at the site of the research partner and sponsoring company; this provided the researcher with a natural environment to test and validate the framework, benefitting from immediate and constructive feedback from the project stakeholders. The stakeholders involved in this case study remain the same as in the previous chapter, with selected employees of Knowsley Safari applying the framework to their business operations and using the supporting tools (referenced in Appendix D1 and D2) to help achieve some of the tasks.

The case study discussed within this chapter is broken down into two main phases, involving a field study based on the site of the research industrial partner and a desk-based research and development phase where a carbon reduction plan is developed by following the steps outlined in the carbon management framework (CMF-V3). The researcher thought it was vital to test the framework developed on a real-world case study that fit within the remit of the intended target user. Several limitations were identified throughout the process and discussed in this chapter's latter stages. Finally, reviewing the validation findings concludes the study with some more interesting findings discussed.

6.2 Research Design – Reflecting on the Effects of the Solution

> ***Validity can be defined as the quality of being well-grounded, sound, or correct, especially when referring to a theory.***
>
> (Mirriam-Webster, no date)

As Chapters 3 and 5 emphasised, testing and validating the newly developed carbon management framework was essential to demonstrate its effectiveness and applicability. This process is pivotal for confirming the framework's validity and understanding whether it successfully fulfils its stated aim and objectives. With this validation, any limitations identified in the framework can be adequately justified and addressed.

It is first essential to remind the reader of the aim and objectives of the framework development:

Primary Aim: *To introduce a novel methodology for implementing carbon management practices within medium-sized organisations based in the UK.*

To achieve this aim, four objectives[1] set out a criterion to be met during the development phase:

Framework Development Objectives:

- *To create a systematic process for carbon management aimed at net-zero operational carbon for SMEs.*
- *Prioritising fabric and energy efficiency to minimise energy demand and associated emissions.*
- *Creating an intuitive framework seamlessly integrated into a company's business model.*
- *Focusing on educating employees and customers about carbon management, alongside implementing training for changes in standard operating procedures (SOPs).*

6.2.1 Rationale for Case Study Design

To validate the effectiveness of the carbon management framework and ensure it meets its objectives, a 12-month case study design was strategically chosen. This

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[1] *These objectives differed from the overarching research objectives and were explicitly designed (refer to Section 5.3.2) to support the development of the novel framework.*

approach is well-suited for real-world applications, as it offers a natural setting for pragmatic data collection and is adaptable to qualitative and quantitative research methods (Yin, 1989; Stake, 1995). The choice of a case study design is instrumental in obtaining in-depth insights and testing the framework in a realistic context.

The case study method provides several benefits essential for the robust testing of the new framework. These include:

- **Ideal for Testing Reliability:** It ensures the operational reliability of the developed framework.
- **Highlighting Limitations:** It allows for the identification of major limitations that might necessitate future refinements.
- **Practical Application:** Demonstrates the framework's applicability and effectiveness for the intended target audience.
- **Meeting Stakeholder Expectations:** Helps in fulfilling the expectations and requirements of the industrial partner, integral to the research project.

While the case study approach offers substantial benefits, it is essential to recognise its limitations. A significant concern is the potential limitation in the generalisability of the findings. Testing the framework within a single case study can restrict its applicability to other organisations, particularly those operating in different sectors. Queirós et al. discuss further limitations, including ethical considerations around confidentiality and the challenge of designing a case study that is universally applicable across diverse business types.

6.2.2 Collaboration with an Industrial Partner

Given the nature of this research and the collaboration with industrial partner Knowsley Safari, the researcher believes this would be the most optimal approach to testing the newly developed instruments. Continuing the pragmatic approach taken throughout the rest of this thesis. Knowsley Safari set out an ambitious goal at the start of this research to become net-zero in its operations. Additionally, the company wanted to be able to contribute to the education of its employees and customers, especially given its unique position as a zoological safari park, which allows them to disseminate and educate in a friendly environment. Their business model focuses on providing quality education to the younger generation in a fun and interactive setting.

6.2.2.1 Rationale for Chosen Site

Knowsley Safari, a UK-based zoological park, served as an excellent testing ground for the research due to its diverse operations and services. At the core of the business is a 550-acre zoological safari site, homing many animals from around the world to entertain and educate the public. In addition to the core business operations, the company offers its visitors several additional services, including dining facilities, live performances, amusement rides, a walking trail, a boating lake, and an education centre. This diverse business model provided a complex yet enriching environment for applying and testing the carbon management framework. Detailed in Table 6-1, he variety of buildings and infrastructure offered a broad range of scenarios for applying the framework.

Furthermore, Knowsley Safari's commitment to research and conservation further enhanced its suitability as a case study site. The organisation’s dedication extends beyond the welfare and conservation of its animals to include broader environmental concerns such as biodiversity and sustainability. This alignment with environmental objectives made it a fitting context for testing a carbon management framework focused on environmental impact reduction.

Table 6-1. Types of buildings and infrastructure applicable to field study at Knowsley Safari

Building Types	Infrastructure (requiring energy)
Office block	Amusement park
Educational building	Electric fencing
Conference centre	Cold Rooms
Auditorium	
Animal houses	
Fully-equipped restaurant	
Cafes	
Shops	
Toilet blocks	

6.2.3 Further Design Limitations

The researcher acknowledged potential challenges in thoroughly testing and implementing each step of the proposed carbon management framework within the research project's timeframe. Careful planning was essential, given the necessity to complete all work within the allocated period. The primary concern was to ensure that the 12-month study was efficiently designed to encompass a full calendar year's data, crucial for a comprehensive seasonal analysis.

The framework, as detailed in Chapter 5, adopts a structured three-phase approach to carbon management:

Phase 1. Base Case – Energy & Carbon Accounting

Phase 2. Business Case – Carbon Reduction Plan

Phase 3. Action! – Strategic Implementation

The first two phases were expected to be achieved during the time available; however, phase three (strategic implementation) may prove challenging as this was to be executed by the industrial partner over several years.

The 12-month study period was critical for analysing energy data across different seasons, allowing for a correlation between seasonal variations, energy consumption, and associated carbon emissions. This duration was deemed sufficient to thoroughly test the elements within the framework's first two phases, providing valuable insights into the practical application and effectiveness.

6.2.4 Supporting Tools

As mentioned in Section 5.8 of Chapter 5, two bespoke supporting tools were developed to specifically assist Knowsley Safari to achieve their net-zero targets. While these tools are not integral to the framework's effectiveness, they serve a significant supportive function. It is important to note that for organisations other than Knowsley Safari looking to implement the CMF-V3, a variety of alternative tools (Carbon Trust, 2019; DEXMA, 2023; Net Zero Now, 2023; SME Climate HUB, 2023; The Carbon Trust, 2023) are available that can similarly aid in the framework's application. These tools are not critical for the efficacy of the carbon management framework (CMF-V3), rather they play a supportive role. The two tools have been mentioned throughout this chapter as they played a key role in supporting Knowsley Safari to achieve their net-zero targets and were a result of the collaboration on the project. Details of the two supporting tools can be found in the following appendices:

Appendix D1

1. **Carbon Management Questionnaire (CMQ)** - a screening survey designed to support the auditing and data collection process of a company's operations, help define building parameters, and improve understanding of what should be accounted for when performing an operational carbon assessment.

Appendix D2

2. **Carbon Management – Statistical Analysis Model (CM-SAM)** - a data analysis tool for assessing a company's operational carbon emissions, with additional features to run a carbon and financial analysis of carbon reduction measures.

While these tools were specifically tailored for Knowsley Safari, they exemplify the type of support mechanisms that can be utilised alongside the CMF-V3 to enhance its practical application. They demonstrate how targeted tools can effectively complement a comprehensive carbon management framework, aiding SMEs in their efforts to reduce carbon emissions.

6.3 Part 1 - Field Study Methodology

A field study was designed as the most appropriate method of testing the steps in phase 1 of the CM framework (as shown in Figure 6-1). The first phase of the novel carbon management framework outlines the steps required to complete a business's energy and carbon assessment.

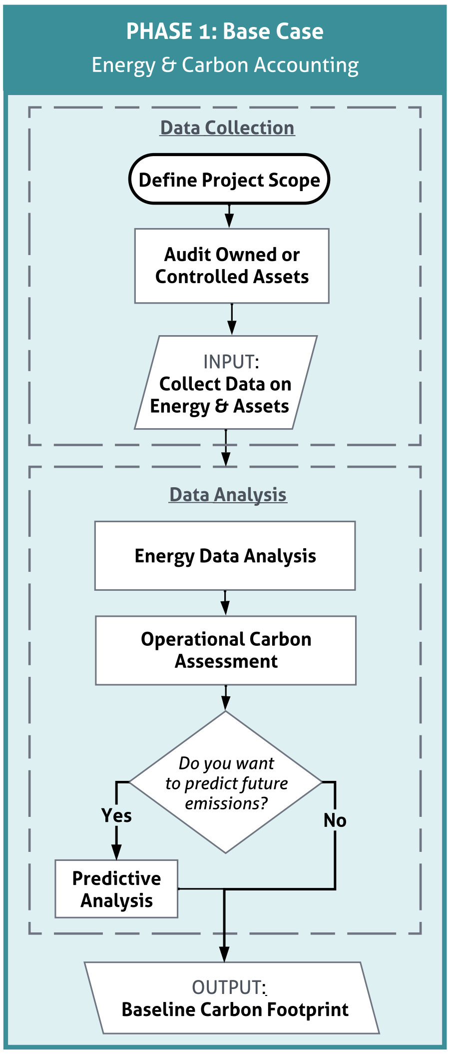

Figure 6-1. CMF-V3 - Phase 1: Base Case

To test each step of the framework, the field study aimed to define the relationship and show the effect of seasonality (the independent but uncontrollable variable) on energy consumption (the dependent variable).

The testing methods used for the field study were aligned with the systematic process outlined in phase 1 of the framework (see Figure 6-1), and consisted of the following four steps:

Step 1: ***Project Scope*** - defining system boundaries, data parameters, study time frame, and calculation methods.

Step 2: ***Site Audit*** – gathering information on the business's energy-consuming assets, including quantity, age, fuel type, usage patterns, and more.

Step 3: ***Data Collection*** – measuring the energy consumption of assets through sub-metering, using specialist energy monitoring equipment.

Step 4: ***Statistical Analysis*** – compiling, cleansing, transforming, and modelling measured energy data to perform a carbon analysis.

6.3.1 Step 1.1 – Project Scope

To begin with, business operations of the business were considered and any activities that may have an impact on carbon emissions. At this stage, a company may wish to understand the total impact of its organisation, not only relating to operational procedures but also considering the impact of supply chain decisions that may contribute to the company's value chain emissions (scope 3). Life Cycle Assessments (LCA) and Environmental Impact Assessments (EIAs) are two commonly used methodologies for understanding the whole-life impacts of any given company, product, process, or material (European Environment Agency, no date; Crawley and Aho, 1999; Tukker, 2000; Rybaczewska-Blażejowska, Palekhov and Rybaczewska-Błażejowska, 2018; Liebsch, 2020).

Given the framework's scope developed during this thesis, these more sophisticated and complex methodologies for defining a company's carbon impacts were irrelevant. Instead, the Greenhouse Gas Protocol (WBCSD and WRI, 2004) was the preferred approach for setting the project scope. As discussed in previous chapters, the protocol sets out standards for establishing a corporate emissions inventory. For this field study, parts of the protocol were adopted to help guide the project scope, with the three following elements to be determined:

a. Defining business goals and key drivers

b. Setting system boundaries

c. Outlining project targets

To determine these three elements of the project scope, it was vital that discussions were held between key stakeholders. To support Knowsley Safari in collecting the required information, a carbon management questionnaire was developed (refer to Appendix D1 for CMQ), to help understand the information required to establish a project scope.

It was first essential to specify the business goals of the research partner and study participant, Knowsley Safari, to determine the drivers for the carbon management project. This involved defining the goals that fit the company's ethos and business model.

Secondly, system boundaries were recognised, including setting a baseline assessment period and defining organisational and operational boundaries (see Table 6-2), aligning to the Greenhouse Gas Protocol.

Table 6-2. Carbon Management System Boundaries

Organisational boundaries	Requires a company to determine which parts of the business structure is to be accounted for. This typically varies for every business and depends on legal and financial company structures and can include wholly-owned operations, incorporated and non-incorporated joint ventures, subsidiaries, franchises, and others (WBCSD and WRI, 2004).
Operational boundaries	Involves identifying the sources of emissions associated with the business's operations, categorising emissions as direct or indirect, and determining the scope of accounting and reporting for indirect emissions (WBCSD and WRI, 2004).

6.3.2 Step 1.2 – Site Audit

Once the project scope was defined and all relevant stakeholders agreed, a site audit was conducted to formally record information regarding the company's energy-consuming assets. For this step, the carbon management questionnaire (CMQ) was utilised (refer to sections 3 and 4 of CMQ in Appendix D1), providing questions to guide the user in auditing assets.

The audit required the company to gather and record information on the operational infrastructure and the energy sources consumed on the site. Table 6-3 highlights the types of assets audited and follows the structure of the CMQ.

Table 6-3. Company Audit: Energy-Consuming Asset Categories

Asset Types
Building & site information
Building fabric
Lighting
Heating & cooling systems
Office equipment
Catering equipment
Industrial/commercial refrigerants
Specialist equipment and machinery
Vehicles
Energy Demand

In addition to helping create an asset register, the CMQ was used to pre-assess the company's energy records, highlighting the sources of energy procured and consumed on the site. This supported the next stage of work, which involved collecting and analysing energy data to compute baseline carbon emissions.

6.3.3 Step 1.3 – Data Collection

Following the site audit, the next step was to collect data for two key purposes: the first was to fulfil the goals of the research partner through a comprehensive carbon assessment of their operations, and the second was to ensure that all components of the proposed CM framework were thoroughly tested. The data collection process consisted of the following steps:

1. Understand the data required to achieve all study objectives.
2. Review the available data types through energy bills, databases, and company records.
3. Understand the metering systems currently installed on the site.
4. Identify significant energy uses (SEUs).
5. Set up sub-meters on SEUs.
6. Periodically record and obtain required data.

The types of data collected during the field study can be found in Table 6-7, and consisted of the following data types:

- **Energy consumption data** - collected monthly bills from the energy provider and measured energy data from sub-meters installed (see section 6.3.3.1 for more details).
- **Asset Information** – taken from the asset register established during the previous step.
- **Weather data** – information gathered from internet sourced weather databases.
- **Company Information** – all data collected directly from company files and databases.

To thoroughly test the framework developed, the researcher suggested that 12-months of data collection would provide a comprehensive analysis of operations and show the impact of seasonality on energy consumption. It was first essential to identify the type of data required to calculate carbon emissions and any additional data that may prove helpful during the analysis stage.

After identifying the available data types, it was important to understand the technical arrangement of the existing energy substations and meters installed on the site. A map of the site was developed, including where each of the sub-stations and meter points were located and which assets, they provide power to (found in Appendix E1). Only then could the significant energy uses (SEUs) be identified. SEUs are a concept taken from ISO 50001: Energy Management Systems, where the standard defines a significant energy use as something "accounting for substantial energy consumption and/or offering considerable potential for energy performance improvement" - (ISO, 2018). For the field study, SEUs were identified initially through the site audit and confirmed through discussions with the site's facility team. Identifying SEUs enabled the company to select which assets would benefit the most from energy sub-metering, as discussed in section 6.3.3.1.

6.3.3.1 Measured Energy Data

As the study's primary aim was to test and validate the novel CM framework, the researcher thought it would be useful to gather as much disaggregated data as possible, allowing each stage of the framework to be thoroughly tested and providing the additional benefit of greater granularity. A 12-month energy study gave enough time to install sub-meters, allowing energy usage patterns of the site's significant energy uses (SEUs) to be independently monitored. Significant energy users and consumption patterns were determined based on findings from the energy pre-assessment completed during the previous step. Energy-consuming assets were sub-metered to help disaggregate data and allow for a more controlled approach.

6.3.3.2 Sub-meters

It was only necessary to sub-meter assets powered by grid-connected electricity, as systems powered via gaseous or liquid fuels tended to have a specific sub-metering system pre-installed. Non-invasive energy loggers, capable of measuring energy consumption without disconnecting any systems, were installed onto circuit breakers, as shown in Figure 6-4. The company could easily install this equipment without any costly and timely installations, making it an ideal choice for an SME wanting to sub-meter its operations.

Utilising energy monitoring equipment (see Table 6-4), onsite pre-installed meters, and billing records, energy data was collected at the end of each month for the 12-month study period. In addition to energy data, as previously mentioned, asset registers, weather data, and company information were gathered to build a comprehensive picture of the company's onsite operations. Table 6-4 shows the energy monitoring equipment used for the study.

Table 6-4. Energy monitoring equipment used in field study.

Equipment Model	Qty	Current Capacity	Cost/Unit
Tinytag Energy Logger Kit (TGE-0001)	1	0-2000A	£995.00 (excl. VAT)
Efergy Engage Sub-metering Kit combined with Engage Hub	10	0-200A	€74.34 (Inc. VAT)

6.3.3.3 Tinytag Energy Logger

For the field study conducted at Knowsley Safari, a *Tinytag* (TGE-0001) energy logger from *Gemini Data Loggers* was utilised to monitor the energy consumption of large equipment and machinery. The non-invasive flexible current coils (A) connect to the energy logger (B) to measure current for spot checks or longer-term monitoring. This device, chosen for its high current capacity of 0-2000A, allowed for effective monitoring across various equipment types on the site.

However, the research faced limitations due to the high cost of the logger (refer to Table 6-4), which restricted the budget to a single unit. Consequently, the logger had to be periodically rotated among different equipment for monitoring, posing potential challenges to data collection continuity and consistency. Despite this, the *Tinytag* energy logger, with its claimed accuracy of 1% of reading ±0.5A (above 10A) (Gemini Data Loggers, 2014), was a valuable tool for energy monitoring during this study, effectively balancing capability with the constraints of the research budget.

Figure 6-2. Tinytag TGE-0001 Energy Data Logger

6.3.3.4 Efergy – Sub-Metering Kit

To address the cost constraints associated with the *Tinytag* energy loggers, the researcher opted for *Efergy engage* sub-metering kits shown in Figure 6-3) as a more budget-friendly solution for energy monitoring. These loggers were used to monitor the energy consumption of most equipment, except for high-demand amusement rides where the *Tinytag* was necessary. The *Efergy* system comprises three key components: a non-invasive current sensor (A) clamped around an electrical load's supply line for current reading, a wireless transmitter (B) to relay data, and an *engage hub* (C) that can collect data from multiple sensors and transmitters, allowing real-time[2] energy data accessed via an online portal (Efergy, 2017). Figure 6-4 shows one of the devices connected in three-phase at Knowsley Safari’s site, hidden inside a distribution board.

Figure 6-3. Efergy engage wireless electricity monitor and data logger.

The Efergy sub-meters provided a low-cost alternative to the Tinytag energy logger (discussed in Section 6.3.3.3) for equipment drawing a current of up to 200A, which was adequate for most equipment at Knowsley Safari. Their primary benefits included their user-friendly design and affordability, as Table 6-4 highlights, which compares costs with the Tinytag logger. Additionally, the Efergy instruments boast a claimed measurement accuracy of 98%, according to the manufacturer's specification sheet (Efergy, 2017). This combination of cost-effectiveness, ease of use, and reliable accuracy made the Efergy sub-meters an ideal solution for the research's energy monitoring needs, effectively complementing the Tinytag loggers and demonstrating a flexible approach to the research methodology within budgetary constraints.

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[2] *“Real-time” monitoring allows the user to select between10, 15, and 20-second intervals* (Efergy, 2017).

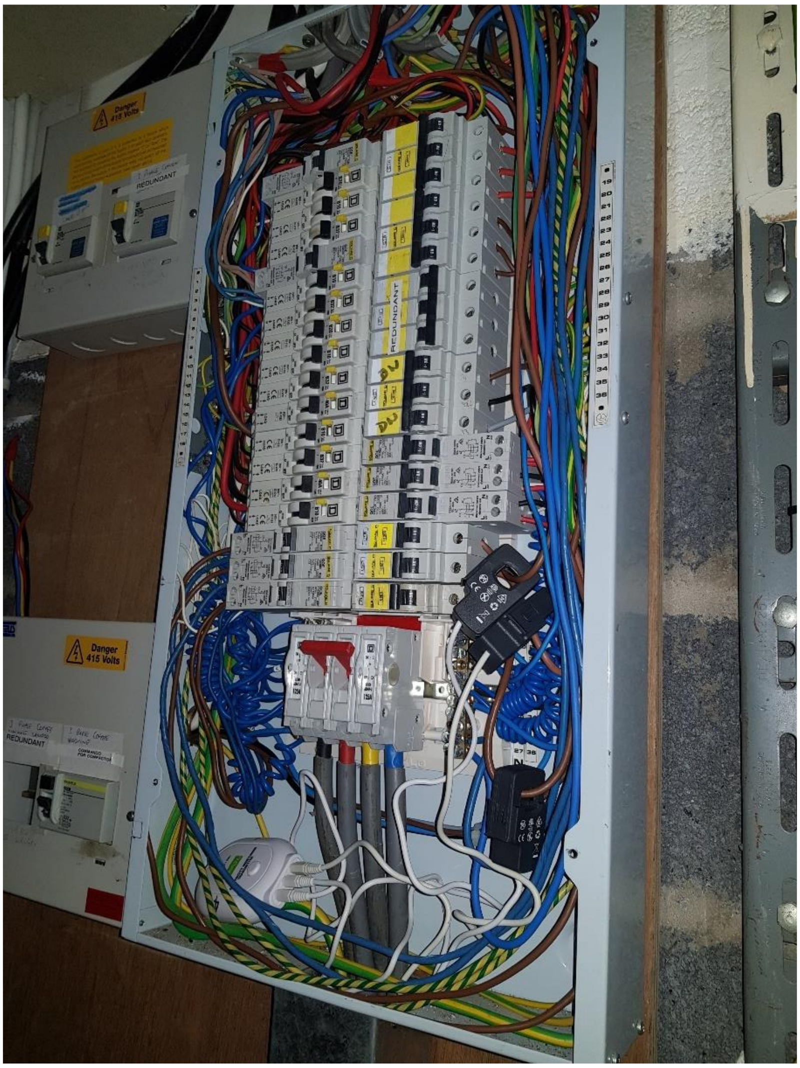

Figure 6-4. Image of Efergy non-invasive electricity sub-meters situated at Knowsley Safari (2019)

6.3.4 Step 1.4 – Carbon Analysis

The time-series data collected during the previous step was periodically collated and analysed to monitor usage patterns, helping to identify trends in energy demand at the site. This process also supported any decisions made when identifying SEUs and allowed for other assets, not already identified as an SEU, to be monitored using the energy loggers and sub-metering equipment (as specified in Table 6-4). Figure 6-5 outlines the data analysis methodology to ensure that the data collected satisfied the objectives described in Section 6.2.

Data analysis followed two key stages. First, data preparation was essential to transform the raw data into meaningful, clean, and valuable information that could be analysed. Following preparation, the data was ready for analysis and validation;

for this specific case study, the aforementioned CM-SAM tool was utilised (refer to Appendix D2 for details on CM-SAM).

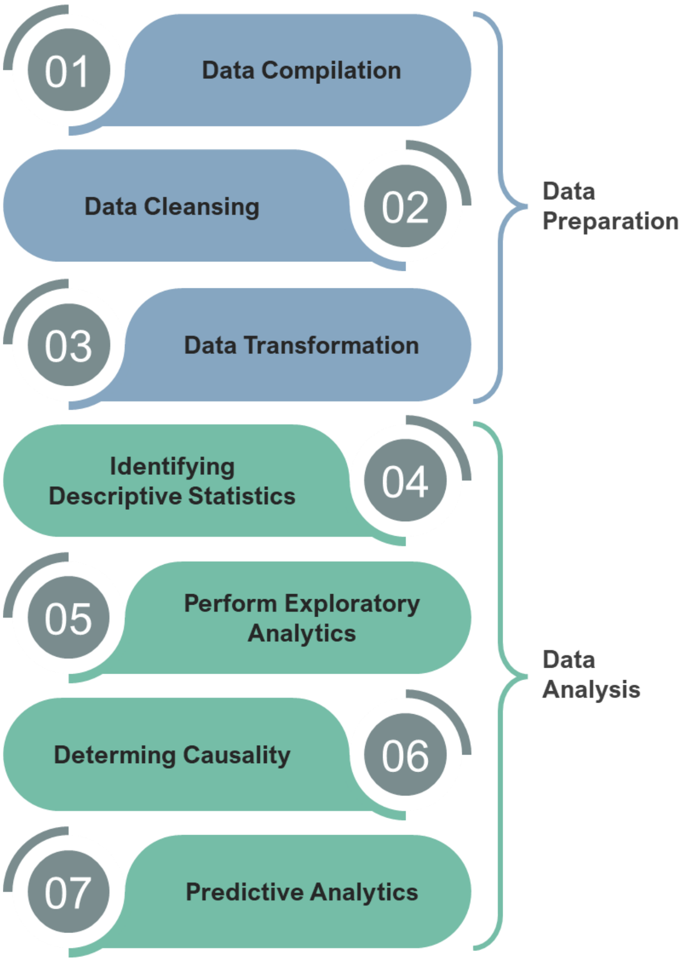

Figure 6-5. Field Study - Data Analysis Process

6.3.4.1 Data Preparation

As shown in Figure 6-5, data preparation was the first stage of the analysis procedure. Data preparation helps to improve the efficiency of analysis by minimising any errors and inaccuracies that can occur whilst collecting and processing. To prepare the data for analysis, the following steps were taken:

i. **Data Compilation** – the collection of raw data within a shared database. For this study, all collected data was input into a singular Microsoft Excel workbook with a separate worksheet for each data type and data sub-type (shown in Table 6-7).

ii. **Data Cleansing** is a procedure used to validate the data, eliminating errors and inconsistencies. Cleaning data is a crucial step that helps to prove the validity of the data collected; it ensures accuracy, completeness, and consistency, removes duplicate entries to guarantee the uniqueness of each data point, and is used to format the data for uniformity. Working systematically when cleansing the data was important, especially given the large quantity and variation of collected data.

iii. **Data Transformation** involves transforming specific datasets from one format to another. To provide an example of the data transformation procedure, the data recorded via the Tinytag energy logger came in the form of current and voltage, both physical quantities of electricity. Electricity, however, is measured in units of power (SI unit – Watts), and power figures are necessary to understand a specific asset's energy demand. In order to calculate scope 1 and 2 carbon emissions, conversion factors provided by the UK government are used. The conversion factor for electricity is given in units of energy per tonne of carbon dioxide equivalent emissions; electrical energy is typically recorded in kilowatt-hours. Therefore, power figures were transformed into energy figures by multiplying the power figure (Watts) by the number of hours (h). Equations 1-3 show the steps to transform the measured energy data into electrical power, energy use, and, subsequently, the equivalent carbon emissions.

Equation 1: Electrical Power

$$Power\ (W) = Current\ (A)\ x\ Voltage\ (V)$$

$$\boldsymbol{P = IV}$$

Equation 2: Quantity of Electrical Energy

$$Energy\ (kWh) = Power\ (W)\ x\ Time\ (H)$$

$$\boldsymbol{E = Pt}$$

Equation 3: Conversion to Emissions

$$Emissions\ (kg\ CO_2e) = Energy\ (kWh)\ x\ Emissions\ Conversion\ Factor\ (kg\ CO2e/kWh)$$

6.3.4.2 Time-Series Data Analysis

Once the data had been compiled, cleansed, and transformed using the CM-SAM, the model was tested by analysing the collected raw data. Data analysis aimed to provide valuable findings within the dataset, highlighting variations that allowed for the assumption of specific parameters to help guide emissions reduction decisions. The analysis phase's desired outcome was determining the carbon footprint of

Knowsley Safari's operations. Four analysis techniques were chosen as the most appropriate for the time-series data gathered, including descriptive, exploratory, causal, and predictive analytics.

i. Identifying Descriptive Statistics

The first analysis method focused on descriptive statistics, helping to summarise and define the dataset's characteristics. The historical data was parsed to help gain a holistic overview, identifying trends, cycles, or seasonal variations. The following provides examples of the types of descriptive statistics analysed:

- Average monthly energy consumption
- Range of energy use over a given period (quarterly or annually)
- Seasonal Variation

ii. Perform Exploratory Analytics

Following the initial descriptive analysis, exploratory analytics were conducted during the field study, utilising various charts to identify trends in energy consumption. This analysis was instrumental in understanding weather patterns and assessing seasonality, providing deeper insights into energy usage and its seasonal fluctuations throughout the year at Knowsley Safari.

iii. Determining Causality

Once graphical charts had been generated, highlighting historical trends and seasonality, causal inference of the time series data was extracted. This process was used to determine the cause and effect of seasonality on energy demand. The causal analysis aimed to determine the impact of weather and seasonality on energy demand and the associated emissions.

iv. Predictive Analytics

The final stage of analysis involved forecasting the time-series data with predictive analytics. The emissions forecasting tool built within the CM-SAM (refer to Appendix D2) was utilised to perform this analysis, taking the historical energy and emissions data and applying an exponential smoothing technique to predict future emissions. This provided a valuable analysis to allow Knowsley Safari to visualise their emissions and the associated trends further, identifying whether emissions were likely to increase or decrease due to historical activities. The Holt-Winters seasonal additive variation (AAA) method (Holt, 1957; Winters, 1960) was applied to the data. This forecasting method incorporates seasonality whilst applying a higher weighting to more recent data points (NIST/SEMATECH, 2022), creating a more realistic forecast of the company's future emissions.

6.4 Part 2 – R&D Study: Developing a Carbon Reduction Plan

Where the field study was designed to test and validate the steps and tools featured in Phase 1 of the carbon management framework (CMF-V3), this secondary study focussed on testing the elements of Phase 2. The work carried out in this phase involved taking findings from the carbon analysis completed during the field study and applying the knowledge learnt to develop a carbon reduction plan for the research industrial partner and case study, Knowsley Safari. The process involved following each step in phase 2 of the carbon management framework (see Figure 6-6).

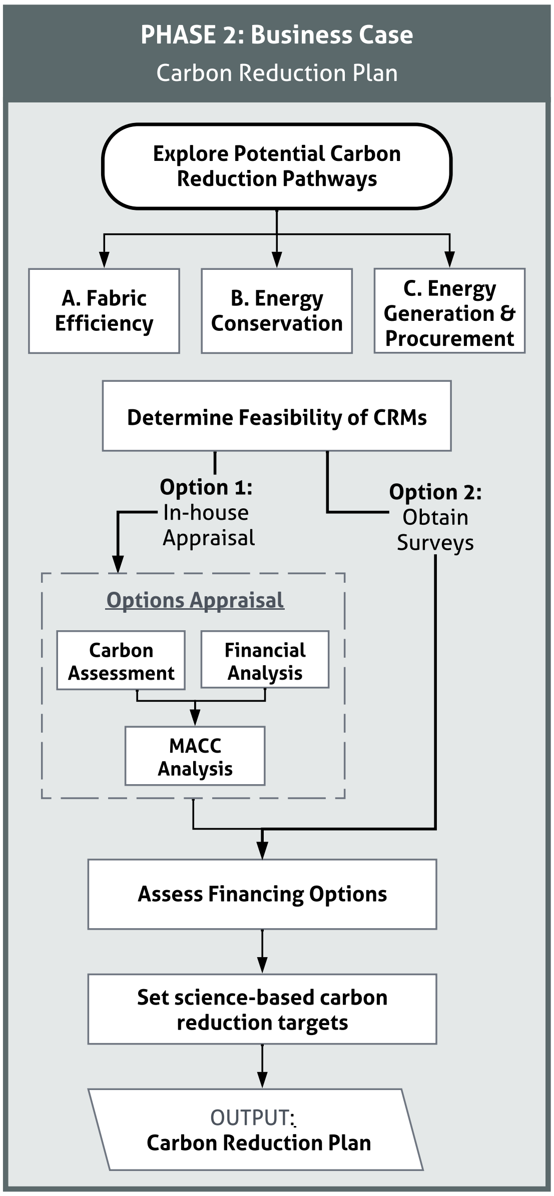

Figure 6-6. CMF-V3 - Phase 2: Business Case

6.4.1 Step 2.1 – Exploring Potential Pathways of Carbon Reduction

As illustrated in Figure 6-6, the first step involved exploring potential pathways of carbon reduction, including fabric efficiency, energy efficiency, and energy generation and procurement. Exploring fabric efficiency measures first required a good base knowledge of the buildings and infrastructure, which was gathered during the audit stage of the field study.

Research into fabric retrofits was undertaken on the buildings that scored low on thermal performance, whether through heat transfer of building makeup or obvious leaks and draughts in the construction. Fabric efficiency is often included as a specific sub-category of energy efficiency (Elsarrag, Al-Horr and Imbabi, 2012; Historic Scotland, 2013; Bonakdar, Dodoo and Gustavsson, 2014); however, it is only one of several types.

Energy conservation can be defined through the evaluation of the rate of energy input versus service output (see Figure 6-7); energy input can increase with more significant system inefficiencies or decrease with optimisation and conservation (Pérez-Lombard, Ortiz and Velázquez, 2013), for this case study, it is the latter that is considered when mentioning energy efficiency.

Typically, three types of energy conservation measures can be considered (Pérez-Lombard, Ortiz and Velázquez, 2013):

1) **Energy efficiency is improved** – measures that decrease energy consumption at a greater rate than the decrease in service output, thus conserving energy whilst improving efficiency.
2) **No change in energy efficiency -** measures that reduce energy consumption without changing energy efficiency due to energy input and services output decreasing simultaneously.
3) **Energy efficiency decreases** – measures where the decrease in energy consumption cannot keep up with the demand for energy for services, thereby decreasing energy efficiency whilst conserving energy.

Figure 6-7. Evaluation of Energy Efficiency

Research into applicable energy conservation measures enabled Knowsley Safari to build up its knowledge of available solutions. This included looking into well-established energy efficiency measures (e.g., light emitting diode (LED) lighting and passive infrared (PIR) sensors) and more innovative solutions (e.g., infrared (IR) panel heaters and heat recovery systems).

The final avenue explored at this stage was energy procurement and generation, where the former refers to sourcing energy from a third-party supplier, and the latter revolves around energy creation. Green energy tariffs[3] were explored as alternatives to the site's existing energy source. Additionally, the suitability of bioenergy was investigated to determine the feasibility of replacing fossil fuels used in buildings and vehicles.

Finally, inquiries were made into onsite and offsite renewable energy generation, including solar photovoltaics, solar thermal, wind turbines, heat pumps and biomass. This stage was purely exploratory to understand the carbon reduction measures (CRMs) available and determine the most appropriate solutions for the next stage.

6.4.2 Step 2.2 – Determine the Feasibility of Carbon Reduction Measures

Taking the knowledge learnt from the previous stage on identifying carbon reduction pathways, the company could work on identifying which measures could be implemented on their site and would align with their business model. At this stage, the framework suggests two options to the user:

- In-house options appraisal

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[3] *Green energy tariffs are where the supplier will match the energy a company demands with purchases of renewables, alternatively the supplier will invest in new renewable energy projects.*

- Obtain feasibility surveys from suppliers and third-party consultants.

Obtaining feasibility surveys often incurs a fee to be paid and typically involves a site visit by a third party to assess the most appropriate carbon reduction measures for a specific site. The in-house options appraisal would require a prospective user to have the required knowledge or access to software or tools that can support it. For this case study, tools were built in the *Carbon Management – Statistical Analysis Model* (CM-SAM illustrated in Appendix D2), designed as a lower-cost option for Knowsley Safari. Measures were identified as applicable based on the research conducted during step 2.1. These measures were then put through the options appraisal tool developed in the CM-SAM.

6.4.3 Step 2.3 Assess Financing Options

Following the options appraisal, where carbon savings and financial metrics were assessed, the framework instructs the user to explore financing options. This area has been ignored during previous studies on carbon management within SMEs; however, it is a vital step required if a carbon reduction plan is to be implemented (Conway, 2015; Finnegan, 2017).

It is understood that some of the common challenges SMEs face is a lack of available funding (Conway, 2015), and strong financial backing is often required to install some of the more technologically complex CRMs (e.g., onsite renewable energy generation). At this stage in the framework, the user is guided to assess all options for financing, including self-funding, loans and grants, asset-based financing, energy service contracts, and leasing.

6.4.4 Step 2.4 – Set Science-Based Carbon Reduction Targets

The final step of Phase 2 guided Knowsley Safari in setting science-based[4] carbon reduction targets. This process involved a meeting with key stakeholders, explaining the concept and significance of science-based targets. Through collaborative discussions, an agreement was reached on specific targets, providing Knowsley Safari with clear and scientifically informed goals.

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[4] *Carbon reduction targets are science-based if they align with the level of decarbonisation required to keep global temperature increase below 2°C relative to pre-industrial levels (CDP et al., 2017; The Carbon Trust, 2018).*

6.5 Application of Novel Carbon Management Framework (CMF-V3)

The following section will present and discuss the results of the field study and the carbon reduction plan outlined in sections 6.3 and 6.4, respectively. The assessment year chosen for the study was calendar year 2018 (CY2018); this would become the baseline period for the business to measure performance against. The carbon reduction plan was developed in 2019 once all data had been thoroughly analysed and was completed toward the end of 2019, with strategic implementation planned for the start of 2020. However, this plan was stifled when the global pandemic, COVID-19, halted operations, and the business had to temporarily close its operations, resulting in a considerable loss of financial income and stability. When the business finally reopened, its focus was to recuperate its losses from the impacts of COVID-19 and focus on business growth. However, most of the results of this study remain valid, apart from the financial analysis completed, which is likely now outdated due to drastic supply chain issues causing a substantial increase in inflation, resulting in all costs increasing across the board.

All data for the study can be found in *Appendix E1*

6.5.1 Project Scope: Knowsley Safari

As outlined in section 6.3.1, the first step taken during the field study involved discussions between project stakeholders to determine the project drivers, system boundaries, and any targets for carbon reduction with the ultimate goal of becoming a net-zero carbon business. Stakeholders agreed on a primary aim:

To achieve net-zero operational emissions by 2025 and, if possible, to deliver the project at net-zero cost.

The principle of net-zero emissions at net-zero cost is based on the holistic analysis of a business, considering its economic activities and environmental impact simultaneously, to identify cost-neutral opportunities to reduce energy consumption and greenhouse gas emissions. This specific project focussed on reducing the company’s operational (or scope 1 & 2) emissions rather than value chain (scope 3) emissions; this is due to decisions made within the business to focus on tackling emissions from operations before taking a more holistic approach to assessing the broader value chain activities. Stakeholders agreed that at this stage, it was more important for the business to “get its own house in order” and to solve some of the inherent problems on the company’s site.

To achieve this aim, three objectives were set out following the structure of the novel carbon management framework (CMF-V3):

- To understand and measure a baseline carbon footprint of the business's operations and to account for scope 1 and 2 emissions, with a future goal to measure scope 3 emissions.
- To design and develop a robust carbon reduction plan that could deliver the primary aim of becoming a net-zero carbon business in scopes 1 and 2 by 2025.
- To ensure that carbon emissions are accounted for and reported on annually, at least until the primary aim is achieved, with the ambition to continue reporting annual emissions beyond 2025.

6.5.1.1 Key Drivers

The key drivers for this project served as the leading factors impacting any future decisions made by the company. The stakeholders agreed that the zoological safari park business has an extraordinary opportunity to engage the public in the complex dialogue surrounding sustainability and carbon management. They thought the business needed to take action and lead by example.

Despite this ambition, activities undertaken by Knowsley Safari span many sectors, including hospitality, conservation, amusements, education and tourism, all of which can present a significant challenge when attempting to operate with sustainability in mind. The stakeholders, however, remained ambitious to deliver a successful carbon management project while retaining their overall goal to educate its customers on conservation and sustainability issues.

In addition to the project drivers, it was necessary to outline the business metrics that may affect any decisions during the project. Table 6-5 outlines some of the specific metrics identified by the project stakeholders.

Table 6-5. Project Additional Considerations

Business Metric	Justification for Consideration of Metric
Financial Decision Indicators	The company wanted to focus on achieving net-zero carbon whilst continuing to grow the business. Despite obvious ambitions to make change and "do good", the company is privately owned and profit-driven; therefore, any changes to operations and policies must also consider financial implications.
Environmental Factors	Given the company's contribution to wildlife conservation, broader environmental factors needed to be considered alongside tackling emissions. This included issues such as biodiversity loss, pollution, water supply, resource depletion, etc.
Well-Being	Stakeholders wanted to retain or improve the well-being standards of its building occupants. Well-being must be considered for the company's employees and customers.
Public Relations (PR)	It was vital for the company that actions taken due to the carbon management project wouldn't damage the business's reputation. Stakeholders wanted to ensure that any dissemination would help to increase the company's positive public image.

6.5.1.2 System Boundaries

The system boundaries comprised organisational and operational boundaries defined in the greenhouse gas protocol. The organisational boundaries set by the business involved understanding the company structure and defining a consolidation approach. Knowsley Safari is a part of the Knowsley Estate, a family-run estate comprising several different businesses; this project was only concerned with the safari park business; the site boundaries are defined in Figure 6-8.

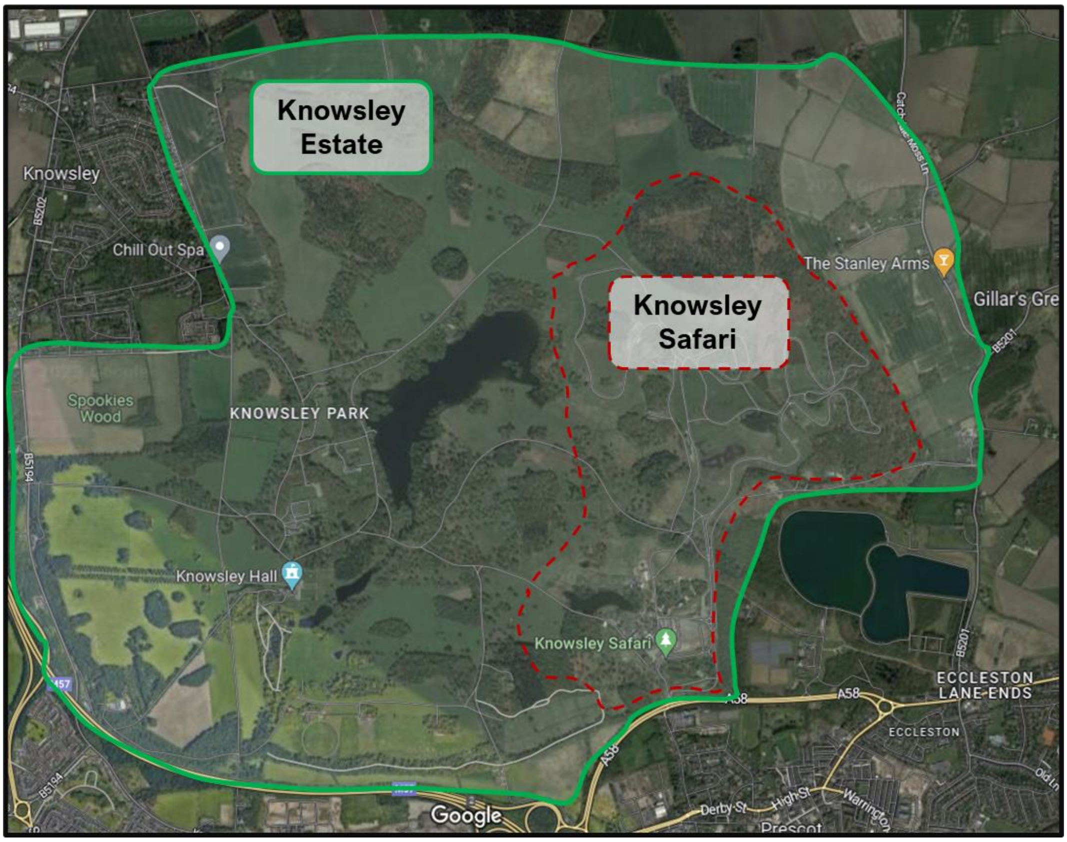

Figure 6-8. Company Operating Boundaries for Field Study

For the operational boundaries, it was essential to define the emissions scopes included within the assessment, in addition to specific emissions sources within the chosen scopes. Operational scope boundaries are defined in Table 6-6 and justifications for any inclusions or exclusions. The emissions scopes listed align with the scope of the Greenhouse Gas (WBCSD and WRI, 2004).

Table 6-6. Operational Scope Boundary for Field Study

Category		**In Scope?**	**Justification for Inclusion or Exclusion**
Scope 1	Company Facilities	✓	Included for the LPG consumed within the operating boundary at Knowsley Safari. LPG is used for onsite heating in multiple buildings and for cooking within the onsite restaurant.
Scope 1	Company Vehicles	✓	Included as Knowsley Safari owns and operates a number of vehicles for use on site and on public roads.
Scope 1	Physical or Chemical Processing	✘	Excluded as Knowsley Safari do not manufacture or process any chemicals and materials (e.g., cement, aluminium, adipic acid, ammonia manufacture, and waste processing).
Scope 1	Fugitive Emissions	✘	Excluded as Knowsley Safari do not operate any refrigeration or AC systems containing more than 4.5 kg of refrigerant.
Scope 2	Purchased Electricity: Location-based	✓	Included for the electricity procured and used within the operating boundary at Knowsley Safari's site. Location-based was chosen as supplier-specific emissions are unknown and so grid averages have been applied to electricity consumption.
Scope 2	Purchased Electricity: Market-based	✘	Excluded as supplier-specific emissions are unknown and difficult to obtain. Grid-averages provide a robust enough emissions value.
Scope 3	All categories	✘	Excluded as part of this initial study due to lack of time and resources, however, the company plans to account for value chain emissions in the future.

6.5.2 Carbon Assessment: Knowsley Safari

The carbon assessment involved collecting and analysing several datasets to compute a baseline carbon footprint for Knowsley Safari; as previously mentioned, the baseline assessment period chosen was calendar year 2018. Table 6-7 highlights which data was deemed necessary for the carbon assessment (mandatory) and which was optional and required only to test the instruments (optional).

Table 6-7. Knowsley Safari - Field Study Data

Data Type	Sub-Type	Carbon Assessment (Mandatory/Optional)	Sub-metered
Energy	Grid-purchased Electricity	Mandatory	Yes
	LPG	Mandatory	n/a
	Liquid fuels	Mandatory	n/a
	Renewables	Optional	n/a
	Bioenergy	Optional	n/a
Assets	Buildings	Mandatory	Partial
	Energy generation equipment	Mandatory	Yes
	Lighting equipment	Mandatory	No
	Heating & cooling systems	Mandatory	No
	Office equipment	Mandatory	No
	Catering equipment	Mandatory	Partial
	Refrigeration equipment	Mandatory	Partial
	Specialist equipment & machinery	Mandatory	Partial
	Vehicles	Mandatory	No
Weather	Local weather files	Optional	n/a
Company Info	Visitor Numbers	Optional	n/a
	Opening Hours	Mandatory	n/a
	Site map (inc. energy meters)	Optional	n/a
	Sales Revenue	Optional	n/a

Knowsley Safari has been operating at the same site since 1971, where the infrastructure has been developed over time; modern equipment has been fitted to the original electricity meter points, with multiple metering substations added throughout the years. It was found that no infrastructure map existed for the electricity meters, so to help understand the energy demand for the site, a set of electricity meter maps was created, which can be found in *Appendix E1.*

6.5.2.1 Energy Demand Review

Electricity, transportation, and heat are the three primary sources that define energy demand for any business (Pistoia *et al.*, 2010). The field study explored all three for Knowsley Safari. Using billing data, seasonal energy demand was assessed for electricity and LPG over two years, while transport was measured annually across the calendar year. The site operates the following energy sources found within Table 6-8:

Table 6-8. Knowsley Safari Energy Sources

Fuel Source	Uses & Demand	Infrastructure
Grid-purchased Electricity	To supply electrical power to the site for lighting, heating, catering equipment, office equipment, electric fences, refrigeration, amusement rides, and other.	Grid-connected
Solar PV	To supplement grid-purchased electricity, uses same as above	Self-generation via 4x roof-mounted PV arrays Array capacity sizes: 40, 10, 10, 4 (kWp)
Liquified Petroleum Gas (LPG)	For heating in the buildings and cooking in the onsite restaurant.	Delivered and stored onsite in above-ground storage tanks
Petrol	For passenger vehicles	Refilling at local fuel stations
Diesel	For passenger vehicles, commercial vehicles, and heavy machinery (e.g., tractors and plant equipment)	Refilling at local fuel stations **and** onsite storage tanks

Figure 6-9 shows the monthly demand for electricity at the site, combining inputs from grid-purchased electricity and solar PV. Additionally, the chart highlights how demand for electricity increases as the average temperatures decrease; it is assumed that this is from an increased demand for heating of the buildings.

Figure 6-10 shows the monthly demand for LPG on the Knowsley site; LPG is used for heating and cooking. Similar to electricity, demand for gas increases as the average temperature decreases; again, this is likely due to increased heating demand.

No monthly data was available for liquid fuels (petrol and diesel) used; therefore, Figure 6-11 cannot show seasonal demand. However, it was discussed that there was likely a slight variation in the energy demand for liquid fuels throughout a calendar year. The chart in Figure 6-11 shows the typical demand for each vehicle or machinery type operated on the site.

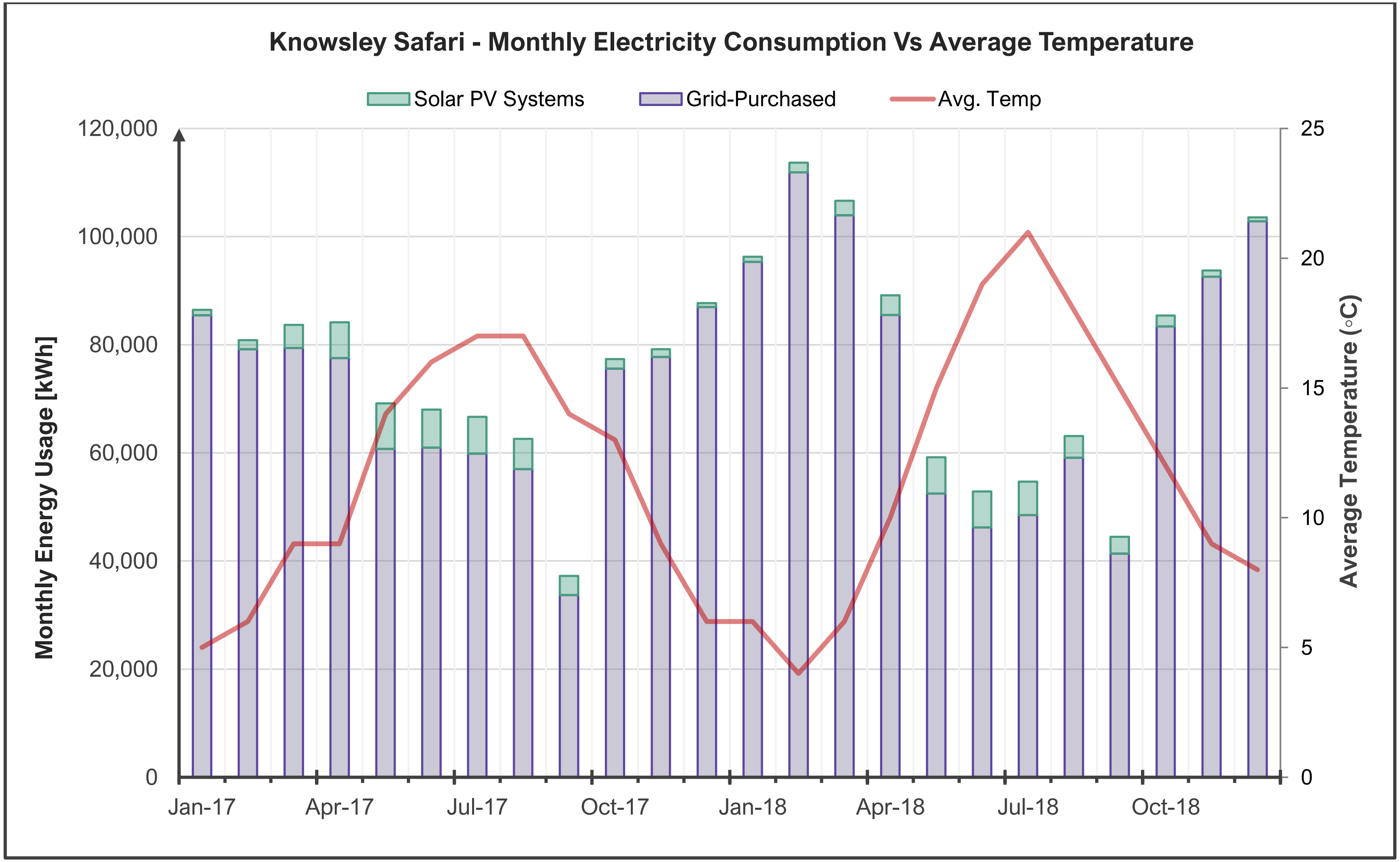

Figure 6-9. Monthly Electricity Consumption Vs Average Temperature at Knowsley Safari

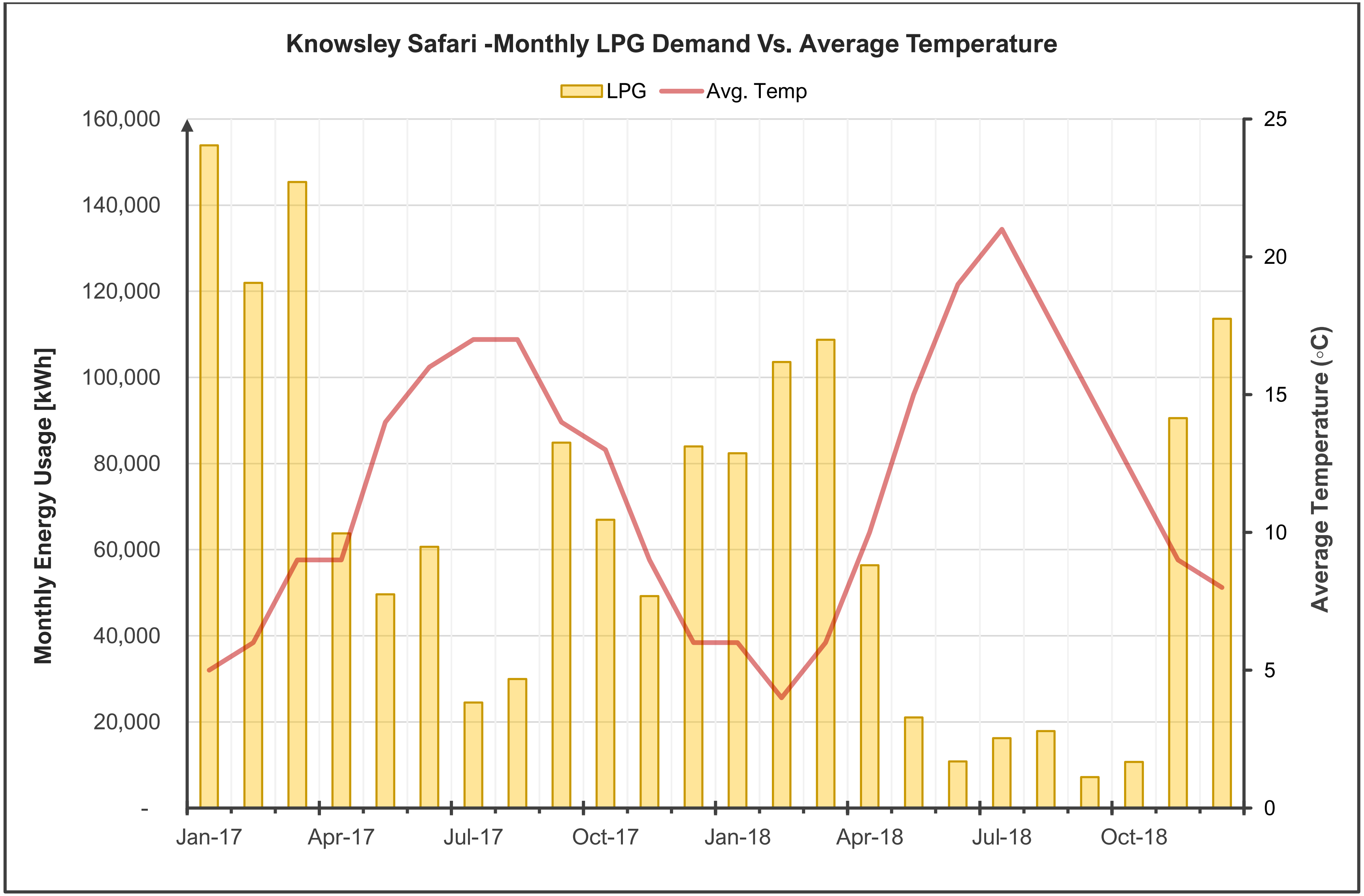

Figure 6-10. Monthly LPG Demand Vs. Average Temperature at Knowsley Safari

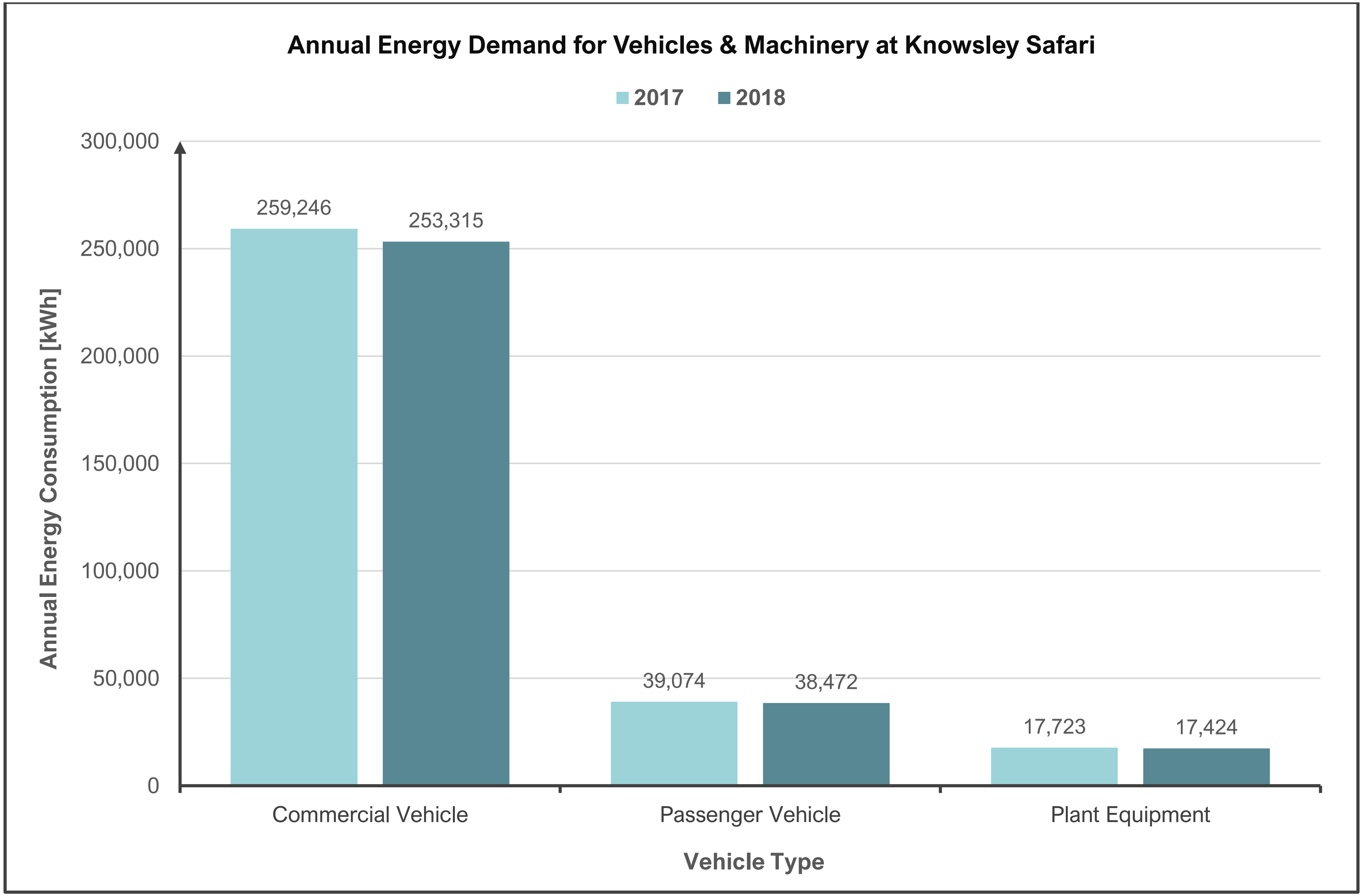

Figure 6-11. Annual Energy Demand for Vehicles & Machinery at Knowsley Safari

6.5.2.2 Significant Energy Uses

Once an overview of the energy demand for the site was completed, as per the results in section 6.5.2.1, significant energy uses were identified from the data obtained using the sub-meters installed (refer to section 6.3.3 for more information on the data collection procedure). The sum of all SEUs should cover at least 80-90% of the energy consumption for a site (ISO, 2018). Through sub-metering equipment and machinery at Knowsley Safari's site, in addition to the information gathered during the pre-assessment site audit, SEUs were identified for the assessment period (CY2018) and are presented in Table 6-9.

Table 6-9. Knowsley Safari SEUs

SEU	Fuel Source	Estimated % of Energy Use	
		Electricity	**LPG**
Comfort Heating	Electricity & LPG	40%	80%
Catering	Electricity & LPG	5%	10%
Water Heating	Electricity & LPG	5%	10%
Lighting	Electricity	10%	-
Refrigeration	Electricity	10%	-
Amusement Rides	Electricity	10%	-
	Total Allocation of Energy	80%	100%

6.5.2.3 Carbon Footprint

Annual carbon emissions were calculated using the energy data collected and multiplying it by the relevant greenhouse gas conversion factors, updated annually and published by the UK government. Firstly, Table 6-1 shows the energy consumption and carbon emissions from the assessment period (CY2018); solar PV has been included to represent the total energy consumption for the business, with emissions calculated to represent the carbon savings through utilising onsite renewable energy generation. Following this, a doughnut chart (see Figure 6-12) was used to represent the split between emission types, with scopes 1 and 2 representing 45% and 55%, respectively. Finally, Figure 6-13 provides a breakdown of emissions in a bar chart, showing the dominance in emissions from grid-purchased electricity.

Table 6-10. Knowsley Safari Energy & Carbon Review for CY2018

Energy Source	Emissions Scope	Energy Consumed [kWh]	Emissions [kg CO_2e]
LPG	**1**	**639,161**	**137,087**
Petrol	**1**	**8,572**	**2,004**
Diesel	**1**	**300,638**	**74,462**
Grid-purchased Electricity	**2**	**923,043**	**261,286**
Solar PV generation	**2**	**88,547**	**(25,065[*])**
	Sum	1,959,961	474,839

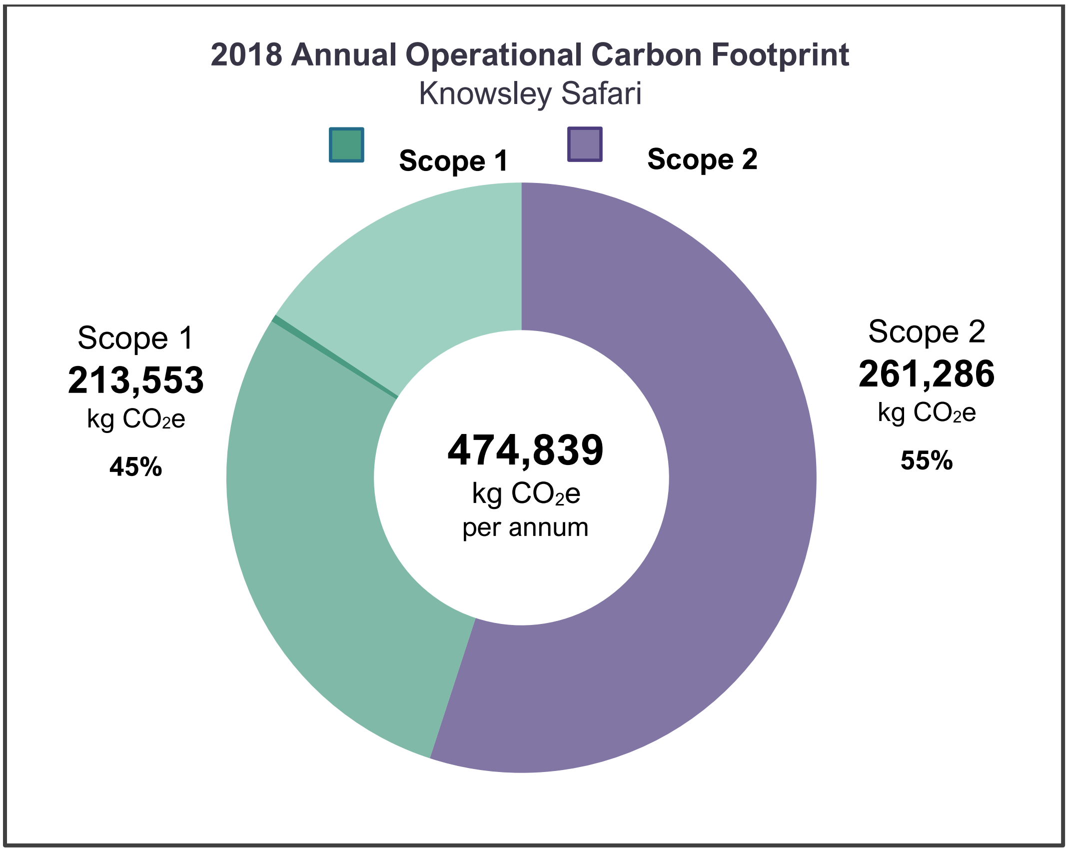

Figure 6-12. 2018 Annual Carbon Footprint for Knowsley Safari

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[*] *Figure shows the q of emissions saved through solar PV generation, this figure is excluded in the total.*

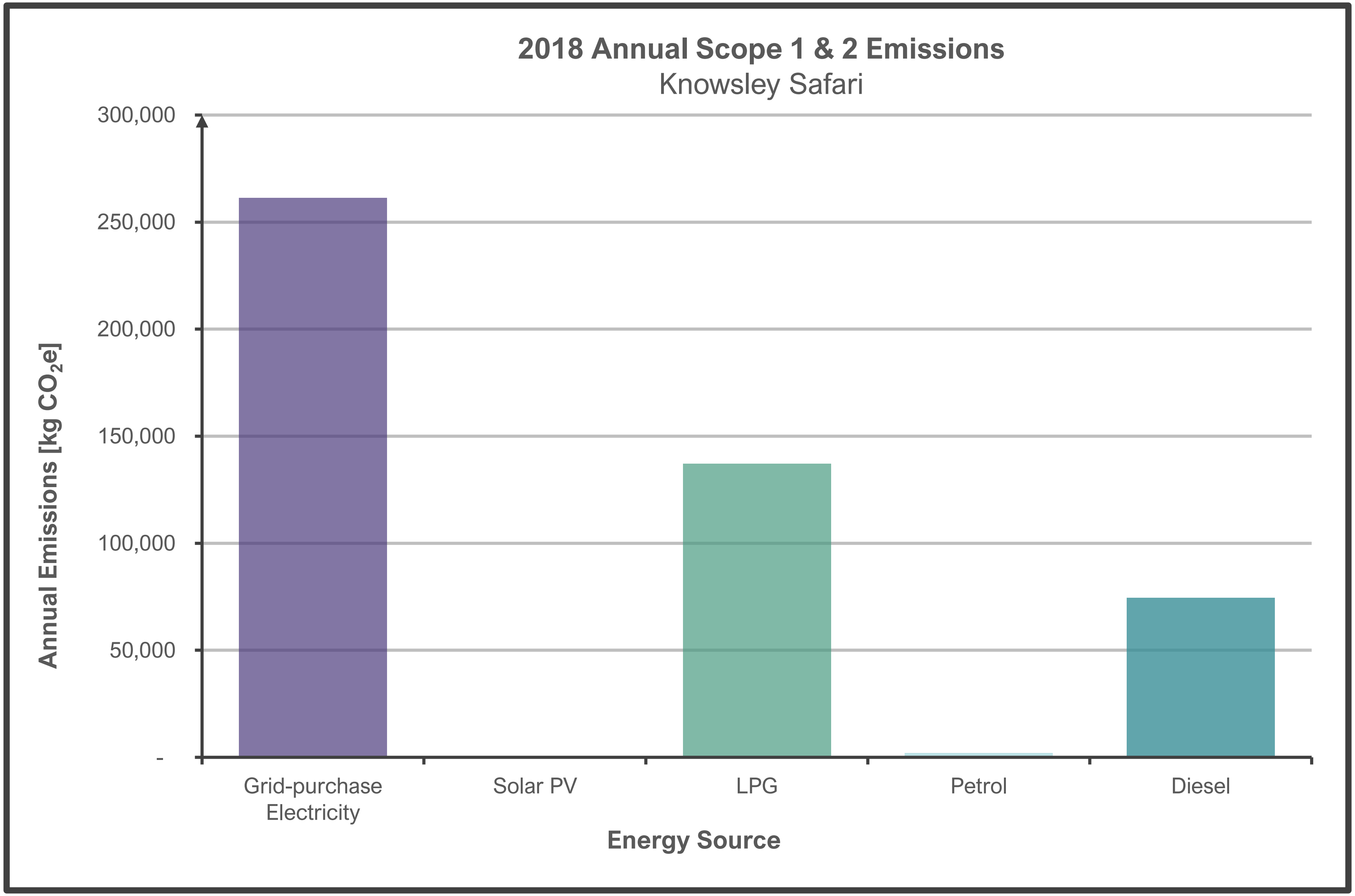

Figure 6-13. Knowsley Safari 2018 Scope 1 & 2 Emissions Breakdown

6.5.2.4 Emissions Forecast

As discussed in section 6.3.4, time series forecasting was used to predict the company's future emissions using the CM-SAM forecasting tool – illustrated in Appendix D2. Time series forecasting considers historical data to predict future outcomes; for this case, a multivariate time series was used to account for seasonality within the historical data. Firstly, a business-as-usual forecast was created to present several predicted variables based on the company's normal execution of standard business operations. The business-as-usual forecast was essential to give a sense of energy performance based on current business operations and historical data.

Figure 6-14 shows Knowsley Safari's predicted emissions based on current business operations; the chart has been created based on historical energy use from 2017 until mid-2019, when data collection was ended. The information displayed within the forecast is known as multivariate time-series analysis (as previously mentioned) and focuses entirely on patterns and pattern changes and thus relies entirely on historical data. The chart displays a linear forecast, calculated using linear regression to compute the trend line, and a seasonal forecast, which considers the seasonal variability in the historical emissions data to provide a more accurate and likely outcome. Analysis shows that overall carbon emissions were predicted to rise if the company operated as usual.

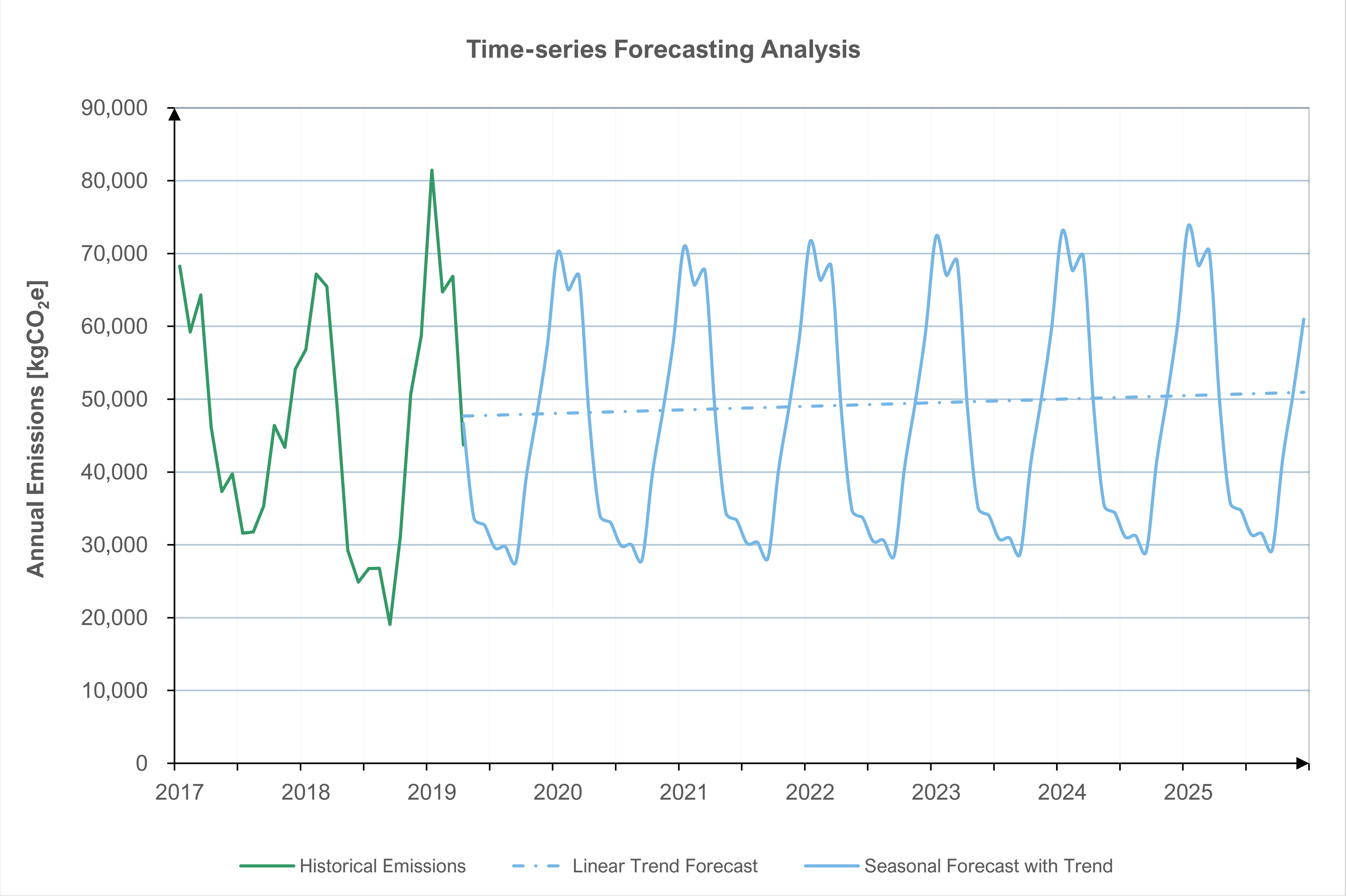

Figure 6-14. Knowsley Safari time-series forecasting analysis for business-as-usual (BAU) emissions

6.5.3 Carbon Reduction Measures: Feasibility Study

Following the energy and carbon assessment, phase two of the testing and validation process comprised desk-based research and a feasibility study to establish a carbon reduction plan for Knowsley Safari. As mentioned, strategic implementation was planned to start in early 2020, giving the business five years to deliver all the necessary actions. Several carbon reduction measures (CRMs) were assessed (see Table 6-11) and reviewed with the findings presented in this section, with measures grouped into the following four categories:

- **Operational** – changes to the standard operating procedures (SOPs) to improve overall efficiency, reduce energy demand, and educate employees.
- **Fabric** – improvements to the fabric of buildings, identifying thermal inefficiencies and improving them to achieve greater energy efficiency.
- **Technical** – solutions require installing new equipment to enhance existing systems or replace old, inefficient systems.
- **On-site Renewables** – renewable energy generated through systems on the company’s land.

CRMs were assessed for potential carbon savings, and financial feasibility analysis was conducted using the financial analysis model integrated into the CM-SAM (illustrated in Appendix D2).

Table 6-11. List of Potential Carbon Reduction Measures Identified for Knowsley Safari

CRM	Description
Fabric Retrofit	Considers the fabric efficiency of existing buildings, including the maintenance and upgrade of building insulation, draught-proofing in leaky buildings, and general building maintenance. A relatively low-cost solution that guarantees savings through quick, simple fixes to existing structures. Improving the fabric efficiency of the existing buildings is of high priority in the early stages of carbon reduction; increasing the thermal efficiency should minimise any heat loss, therefore reducing the amount of energy required for heating.
Energy Efficiency Measures	Exploring the available energy efficiency solutions, including installing sub-metering for energy monitoring, power factor correction (PFC) and voltage optimisation systems to reduce energy loss through the site's electricity network, and a dedicated staff role to maintain energy management and education to the workforce.

Lighting & Controls	Upgrading all lighting to low-energy light emitting diodes (LEDs), combined with intelligent lighting controls, including passive infrared (PIR) sensors, building management systems, and daylight harvesting. The average payback period for low-energy lighting upgrades is usually between 1-3 years and is simple to install.
Infrared Heating	Infrared heating to replace existing gas-powered space heater, providing more efficient heat to the site's "open air" buildings where heat retention is challenging. Infrared heating works by directly heating the thermal mass of a building; in contrast to standard convection heating that warms the air, combined with a 100% renewable electricity source, infrared heating can provide efficient, emission-free heat.
Biomass Boiler	Biomass boilers are a low-carbon and renewable energy source that burns organic matter (mostly wood) to generate a source of heat, or heat and electricity, if combined with a combined heat and power (CHP) engine. Installation of a biomass boiler at Knowsley Safari could provide an alternative to buildings currently heated with LPG-fuelled space heaters. In addition to generating a renewable heat source, biomass boilers are eligible for the UK government's renewable heat incentive (RHI) and would also generate a source of income.
Ground-Mounted Solar Photovoltaics	A large-scale ground-mounted solar photovoltaics (PV) farm could be the perfect alternative to purchasing grid electricity. Knowsley Safari is located on a unique site with a significant amount of land available, making it the ideal location for ground-mounted solar. Solar panels have an expected lifespan of around 25-30 years (if properly maintained); therefore, a suitably sized solar farm could provide the site with 100% renewable electricity for at least 25 years. Mounting solar PV panels on the ground reduces the cost of installation whilst also increasing accessibility for routine maintenance.
Anaerobic Digestion – Combined Heat and Power (AD-CHP) Plant	Anaerobic digestion (AD) works by converting organic matter into useful biogas; this biogas can then be burnt for heat or used as fuel in a combined heat and power (CHP) engine to provide heat and electricity. A reliable feedstock is essential to a profitable AD and may have to be bought from a third-party supplier. The feedstock required can be anything from food and drink waste to animal matter, making it a suitable choice for Knowsley Safari.
Wind Turbine	Onshore wind is prevalent in the UK due to its numerous benefits and ability to produce 100% green energy if positioned in the optimal location. It is a proven technology which is currently the cheapest renewable energy source available to the UK; in addition, it is quick to install and has a relatively long lifespan of around 20-25 years. Wind energy could be an ideal solution for electricity generation at Knowsley Safari due to relatively high wind speeds on site; a wind speed test should be conducted before installation.
Solar Thermal	Solar thermal technology is one of the oldest renewable energy sources and is a reasonably well-established technology. The technology is most commonly used to convert energy from the sun into hot water for heating systems. Solar

	collectors do not require bright sunlight to function, meaning they are still a viable alternative to fossil fuel-based heating systems. Systems are straightforward to integrate into existing hot water systems, meaning little disruption to business operations.
Ground source Heat Pump (GSHP)	Ground source heat pumps (GSHP) are one of the most reliable renewable sources. This is because the ground temperature remains relatively constant, even during winter. The technology can be used to produce hot water and operate warm air heating systems, and there are several different types of systems to suit any site. The technology is relatively expensive to install but has very low maintenance and is easy to run.
Air Source Heat Pump (ASHP)	Air source heat pumps (ASHP) simply take the air from outside and convert it into heat for use within a heating system. Unlike GSHPs, installing ASHP can be pretty straightforward, reducing the initial installation cost. There are two main types of ASHPs: air-to-water systems that send the heat to water-based heating systems and air-to-air systems that produce a flow of warm air that can be used as space heating.
Ultra-Low Emissions Vehicles (ULEVs)	Electric vehicles are rapidly becoming the future of transport, with the UK government introducing a ban on new petrol and diesel vehicles by 2030. Emissions from internal combustion engines are among the most significant contributors to GHG emissions, especially older vehicles. The price of all-electric and hybrid vehicles is swiftly declining and will continue to do so as technology advances. Installation of electric charge points combined with a renewable electricity source would provide the company with financial and environmental benefits.

6.5.3.1 Financial Analysis of Carbon Reduction Measures

In financial analysis, there are several critical indicators to look out for when deciding on an investment, from the project's initial cost to the operation and maintenance. Business is expected to analyse several financial decision indicators (FDIs) depending on the company's requirements. Whether the main interest is to make a quick profit within a few years or to break even over ten years on the basis that other needs are met (such as a reduction in emissions). A comprehensive analysis of the carbon reduction measures (CRMs) and their related financial factors was completed and presented to the company for review. Table 6-12 displays the estimated expenditure, capital and operational, compared to the estimated annual energy savings, reduced fuel costs, government rebate payments, and energy export income. Table 6-12 has been sorted by capital expenditure (CAPEX) in ascending order. A complete list of assumptions and calculations can be found in *Appendix E4.*

Table 6-12. CRM Expenditure Vs. Savings

CRM	CAPEX	Average Annual O&M	Average Energy Savings per Annum	Annual RHI Payments	Annual Export Income	Net Annual Savings
	Expenditure		Savings & Income			
Fabric Retrofit	£6,390	£300	£2,645	-	-	£2,345
Lighting & Controls	£13,460	£146	£10,819	-	-	£10,673
Heating, Ventilation and Air Conditioning	£25,350	£634	£12,000	-	-	£11,366
Air Source Heat Pump	£32,000	£500	£4,285	£2,124	-	£5,909
Energy Management System	£36,354	£3,655	£19,417	-	-	£15,762
Solar Thermal	£54,000	£540	£3,593	£3,294	-	£6,347
Biomass Boiler	£111,000	£16,633	£11,943	£15,550	-	£10,860
Ground Source Heat Pump	£131,700	£500	£9,086	£13,871	-	£22,457
Ultra-Low Emissions Vehicles	£310,000	£0.00	£10,000	-	-	£10,000
Anaerobic Digestion - Combined Heat and Power Plant	£627,000	£58,000	£102,332	£11,520	£2,500	£58,352
Solar Farm	£800,000	£10,400	£155,918	-	£5,918	£151,43
Wind Turbine	£1,100,000	£41,000	£187,660	-	£37,660	£184,320

Table 6-13 summarises each of the CRM's key financial decision indicators computed using the financial analysis model in the CM-SAM (illustrated in *Appendix D2*); the table has been sorted by payback period in ascending order. A complete list of assumptions and calculations can be found in *Appendix E4.*

Table 6-13 assumptions:

- Discount Rate (r) = 5%
- Inflation Rate (i) = 2%
- Assessment Period (t) = 20 years

Table 6-13. Financial Analysis of CRMs

CRM	CAPEX	O&M [20 years]	Payback [yrs]	ROI [5 Years]	ROI [10 Years]	NPV	IRR
Lighting & Controls	£13,460	£2,928	1.3	268.7%	579.6%	£114,208	80.4%
HVAC	£25,350	£12,675	2.2	117.2%	286.3%	£112,302	47.1%
Fabric Retrofit	£6,390	£6,000	2.5	89.9%	219.0%	£22,476	40.7%
EnMS	£36,354	£73,093	5.7	-32.3%	177.0%	£136,526	26.2%
Solar Farm	£800,000	£208,000	6.0	-15.2%	58.2%	£971,711	17.7%
Biomass Boiler	£111,000	£332,660	6.2	-18.0%	20.5%	£30,777	10.2%
ASHP	£32,000	£10,000	6.9	-25.9%	22.8%	£17,334	12.2%
Wind Turbine	£1,100,000	£820,000	8.6	-38.8%	14.1%	£693,055	11.9%
GSHP	£131,700	£10,000	11.6	-31.6%	-2.3%	-£455	4.9%
AD CHP	£627,000	£1,160,000	13.8	-62.1%	-33.5%	-£55,347	3.8%
Solar Thermal	£54,000	£10,800	22.6	-55.9%	-31.8%	-£10,725	3.9%
ULEVs	£310,000	£0	31.0	-85.2%	-72.4%	-£176,550	-3.9%

The chart shown in Figure 6-15 was created to show the estimated capital cost to implement each CRM and compare it to the amount of potential annual carbon emissions abatement. The CRMs are sorted by estimated capital expenditure in ascending order, and the general trend shows that the more spent on initial capital funding, the more significant amount of CO2e can be abated each year, with ultra-low emissions vehicles (ULEVs) being the exception due to the current high cost of hybrid and fully electric vehicles. However, the cost of ULEVs is likely to drop significantly over the next decade as the technology develops and investment increases.

6.5.3.2 Marginal Abatement Cost Curves

A marginal abatement cost curve (MAC curve or MACC) is a straightforward tool to illustrate the economics associated with carbon mitigation. Policymakers extensively use the tool for various environmental issues; increasingly, it aids in decision-making for climate change policy and presents the carbon abatement scenarios relative to the business-as-usual emissions pathway. MAC curves are broken into discrete 'blocks', each representing an individual or set of CRMs (Kesicki and Ekins, 2012; Tempest, 2016; Vogt-Schilb, 2018).

The marginal abatement cost (MAC) measures the cost of reducing one more unit of carbon and is presented on the **y-axis** of the graph:

- MAC is measured in £/tCO$_2$e.
- (-) Negative MAC values demonstrate financial savings, meaning the company will save money (over the assessment period) whilst also reducing carbon emissions.
- (+) Positive values will cost the company money (over the assessment period) to reduce carbon emissions.

The **x-axis**, or the width of the blocks, presents the amount of potential reduction in carbon emissions each year:

- Measured in tonnes of carbon dioxide equivalent, tCO$_2$e.
- The wider each block, the more carbon emissions are abated annually.

The MAC curve, shown in Figure 6-16, was developed for Knowsley Safari's carbon abatement targets in 2025. All measures below the x-axis indicate negative costs for each tonne of CO2e removed; in other words, by implementing these CRMs, the company will reduce operating costs whilst reducing carbon emissions. Measures above the x-axis will cost the company money per tonne of CO2e abated;

however, it is essential to note that the marginal abatement cost has been calculated over six years until the target year of 2025, and specific measures above the x-axis still carry financial savings to the company over a more extended assessment period. The blue dot-dash line on the MAC curve represents the 2018 baseline emissions, meaning theoretically, if all CRMs up to this point are implemented, then Knowsley Safari would be close to achieving their net-zero carbon target by 2025.

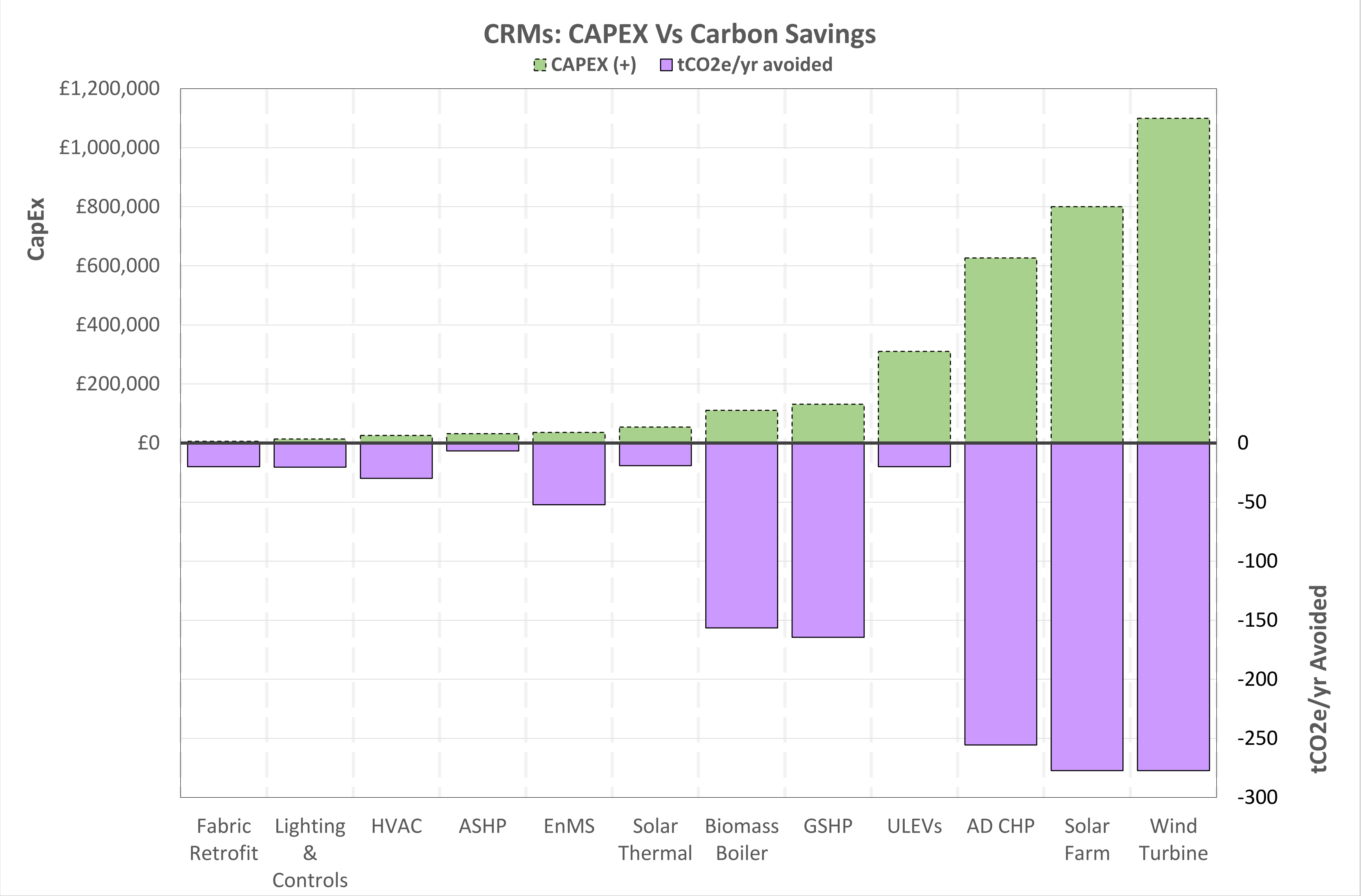

Figure 6-15. Potential Carbon Reduction Measures for Knowsley Safari: An analysis of capital expenditure vs. carbon savings

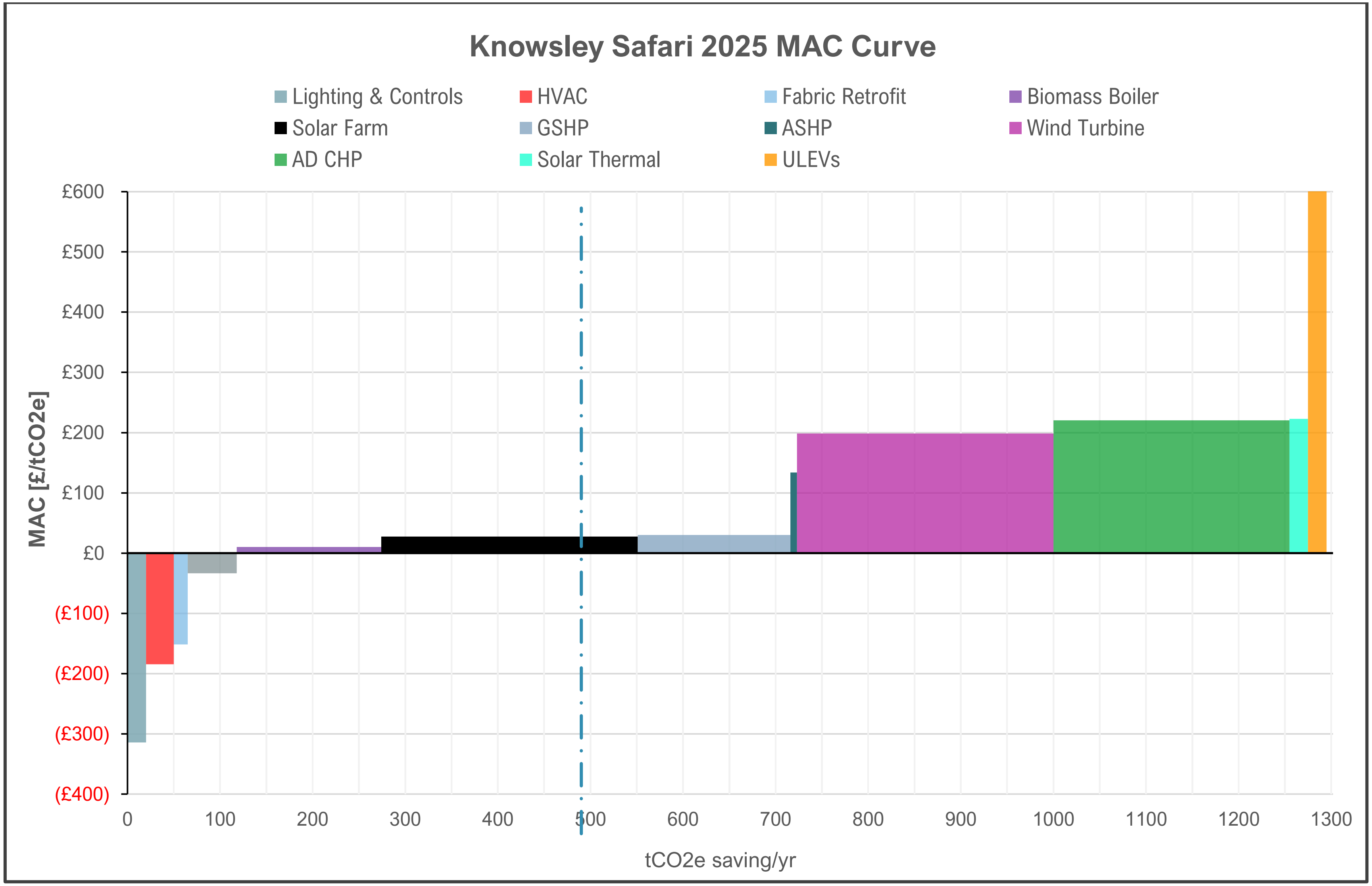

Figure 6-16. Marginal abatement cost (MAC) curve showing proposed carbon reduction measures for operational carbon reduction by 2025.

6.5.4 Carbon Reduction Plan: Knowsley Safari

Developing a carbon reduction plan for Knowsley Safari required strategic implementation considering the following elements[1]:

- Project aim & objectives (discussed in section 6.5.1)
- Baseline carbon footprint (discussed in section 6.5.2)
- Feasibility of carbon reduction measures (discussed in section 6.5.3)
- Implementation priorities
- Critical success factors

The project stakeholders developed and proposed a carbon reduction plan (see Figure 6-17) considering the factors suggested above. A "fabric-first" approach was considered to improve the overall efficiency of buildings on site; this was followed by suggestions for an energy management system to control and monitor energy use. Furthermore, low-energy lighting combined with passive infrared sensors (PIR) would substantially reduce the company's energy demand from lighting. Once a plan for building efficiency had been set, the focus turned toward heating systems, with the stakeholders opting to set a goal to replace existing gas-powered systems when feasible and consider installing a biomass boiler that would provide low-carbon heat.

The next step in the carbon reduction plan would require the company to install a ground-mounted solar photovoltaics (PV) array to provide 100% renewable electricity to operations. In combination with the solar array, the stakeholders discussed the options to install battery storage to provide 24-hour renewable electricity to the site. The stakeholders also discussed the possibility of installing a wind turbine, subject to feasibility, to supplement the solar PV array. In addition to onsite renewable energy generation measures, the analysis showed that supplementary grid-procured electricity would be required, especially during winter when the solar system would struggle to keep up with the required energy demand for heating. As a result, a plan was put in place to switch all electricity tariffs over to a 100% renewable tariff.

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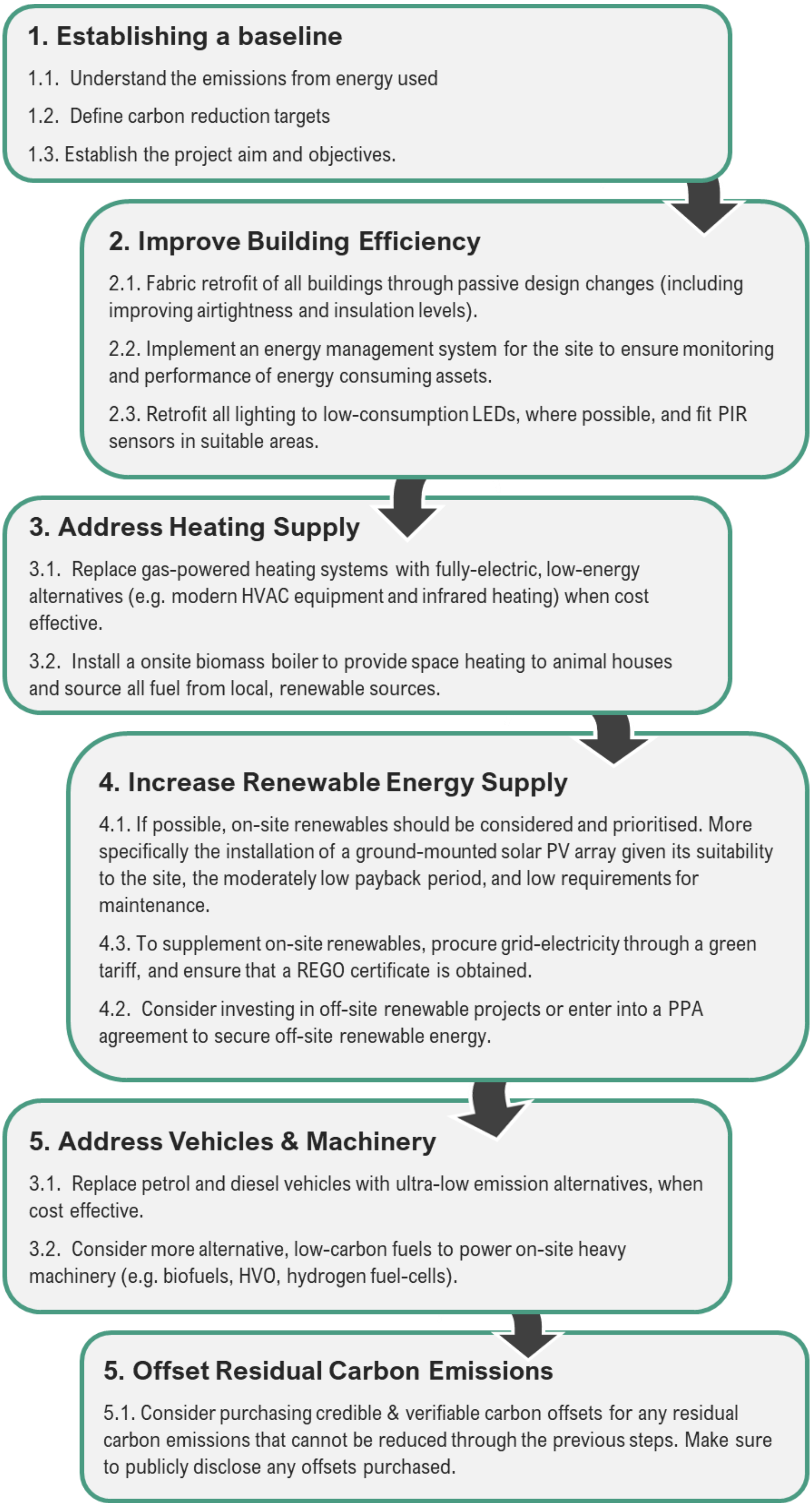
[1] *All of which were either fully established or discussed with stakeholders prior to the strategic development of a CRP.*

The next area to consider in the carbon reduction plan was tackling the vehicles and machinery owned and operated by the business, currently powered by petrol and diesel. Options for replacing vehicles with ultra-low emissions alternatives were a costly option in the financial analysis and would require substantial investment from the company; therefore, it was proposed that this be implemented in a phased approach to allow for capital costs to be spread over several years.

Given the challenge of reducing scope 1 emissions from vehicles and machinery by the company's net-zero target date of 2025, carbon offsets would be required to achieve a net-zero balance of operational emissions from business activities.

A strategic implementation chart of the proposed carbon reduction measures (CRMs) is presented in Figure 6-18, showing the agreed time frame for implementing each CRM. Additionally, the predicted carbon reductions are represented and based on the completed CRM feasibility study (discussed in section 6.5.3). Historic emissions have been forecast to predict business-as-usual emissions, and all carbon reductions have been based on the linear trend forecast, as shown on the chart.



1. Establishing a baseline

1.1. Understand the emissions from energy used

1.2. Define carbon reduction targets

1.3. Establish the project aim and objectives.

2. Improve Building Efficiency

2.1. Fabric retrofit of all buildings through passive design changes (including improving airtightness and insulation levels).

2.2. Implement an energy management system for the site to ensure monitoring and performance of energy consuming assets.

2.3. Retrofit all lighting to low-consumption LEDs, where possible, and fit PIR sensors in suitable areas.

3. Address Heating Supply

3.1. Replace gas-powered heating systems with fully-electric, low-energy alternatives (e.g. modern HVAC equipment and infrared heating) when cost effective.

3.2. Install a onsite biomass boiler to provide space heating to animal houses and source all fuel from local, renewable sources.

4. Increase Renewable Energy Supply

4.1. If possible, on-site renewables should be considered and prioritised. More specifically the installation of a ground-mounted solar PV array given its suitability to the site, the moderately low payback period, and low requirements for maintenance.

4.3. To supplement on-site renewables, procure grid-electricity through a green tariff, and ensure that a REGO certificate is obtained.

4.2. Consider investing in off-site renewable projects or enter into a PPA agreement to secure off-site renewable energy.

5. Address Vehicles & Machinery

3.1. Replace petrol and diesel vehicles with ultra-low emission alternatives, when cost effective.

3.2. Consider more alternative, low-carbon fuels to power on-site heavy machinery (e.g. biofuels, HVO, hydrogen fuel-cells).

5. Offset Residual Carbon Emissions

5.1. Consider purchasing credible & verifiable carbon offsets for any residual carbon emissions that cannot be reduced through the previous steps. Make sure to publicly disclose any offsets purchased.

Figure 6-17. Carbon Reduction Plan for Knowsley Safari 2019

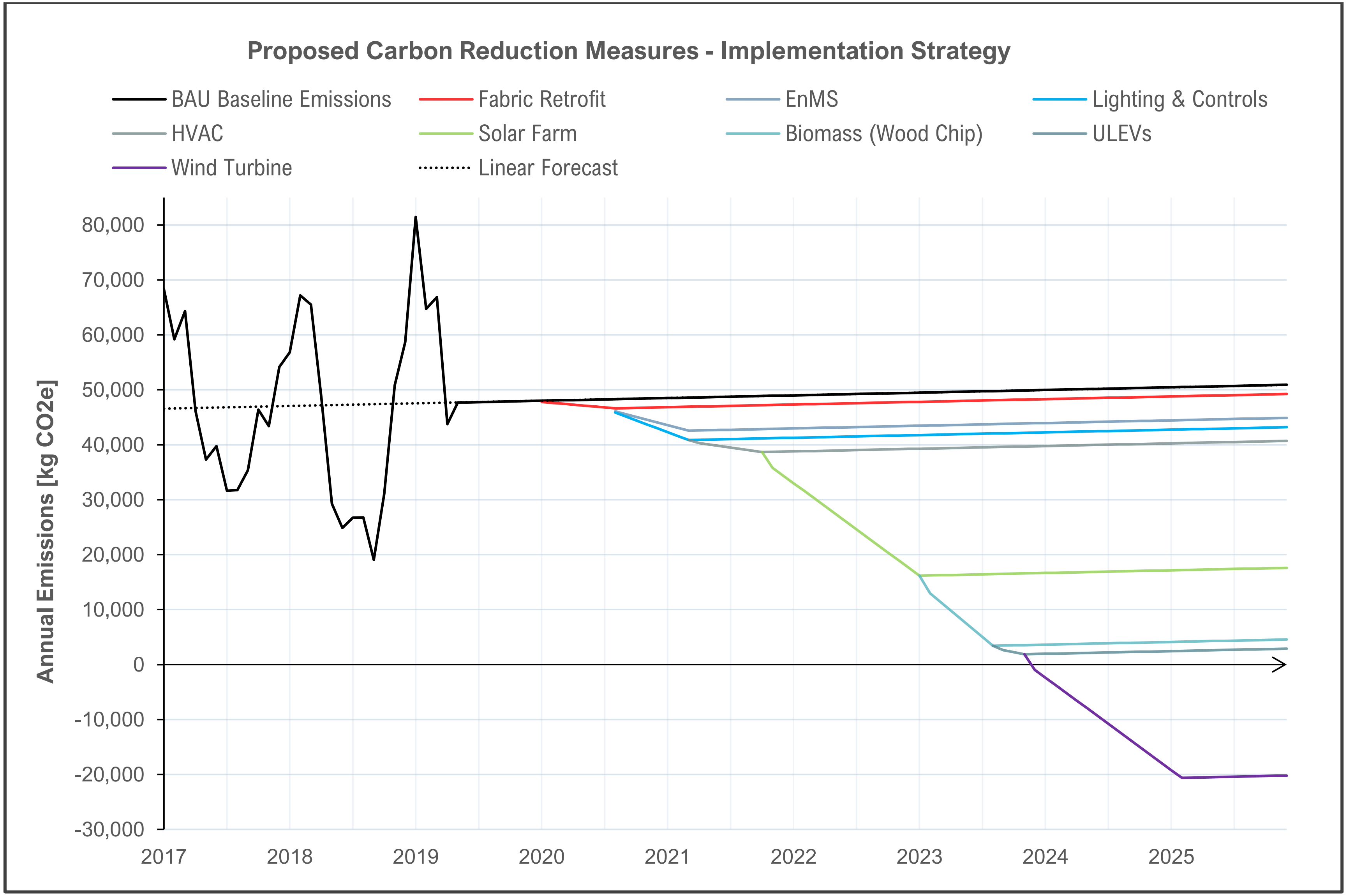


Figure 6-18. Strategic Implementation Plan of carbon reduction measures for Knowsley Safari

6.6 Validation Findings for the Carbon Management Framework

This Chapter's primary focus was to test and validate the novel carbon management framework (CMF-V3) introduced in Chapter 5. The case study was designed to rigorously evaluate each element of the framework, ensuring comprehensive application to all steps, regardless of their immediate necessity for Knowsley Safari.

6.6.1 Identified Limitations and Feedback from Stakeholders

During the validation process, several limitations inherent to new framework development emerged. A significant challenge highlighted by Knowsley Safari stakeholders was the need for additional guidance from the researcher in navigating certain steps of the framework. This finding stresses the necessity for a comprehensive support document in any potential future commercialisation of the framework, especially for complex stages like operational carbon assessment. Despite this, stakeholders noted the framework's systematic and intuitive nature, facilitating a clear process flow.

6.6.2 Generalisability and Case Study Limitations

During the case study design (refer to Section 6.2.3), a further major limitation was identified, resulting from the exclusive application of the framework to a single case study, which also doubled as the research industrial partner and a key contributor during the development phase. This limitation restricts the generalisability of the findings to different business sizes and sectors. Such constraints are typical in case study designs and are coupled with ethical considerations and the challenge of creating universally applicable methodologies (Queirós, Faria and Almeida, 2017).

6.6.3 Challenges in Testing Phase Three

he most significant limitation arose in the inability to test and validate Phase Three of the framework, as shown in Figure 6-19, due to time constraints and the significant impacts of the COVID-19 pandemic. The strategy proposed followed the steps outlined in phase three of the framework (shown in Figure 6-19). In addition to aligning the stages set out, the study produced a strategic implementation chart (see Figure 6-18) for the proposed carbon reduction measures; this provided an outlook into the potential carbon reductions should the company implement all the measures set out. The final two steps of the framework, "*Educate workforce on CM Practices*" and "*Annual Emissions Reporting*," were unable to be validated in any capacity; however, they are relatively straightforward actions that the study participant, Knowsley Safari, agreed could be implemented and would inevitably form part of the company's business model. One of the company's main drivers was the dissemination of any findings to both its workforce and customers; therefore, a certain level of assurance can be assumed for the company when actioning this.

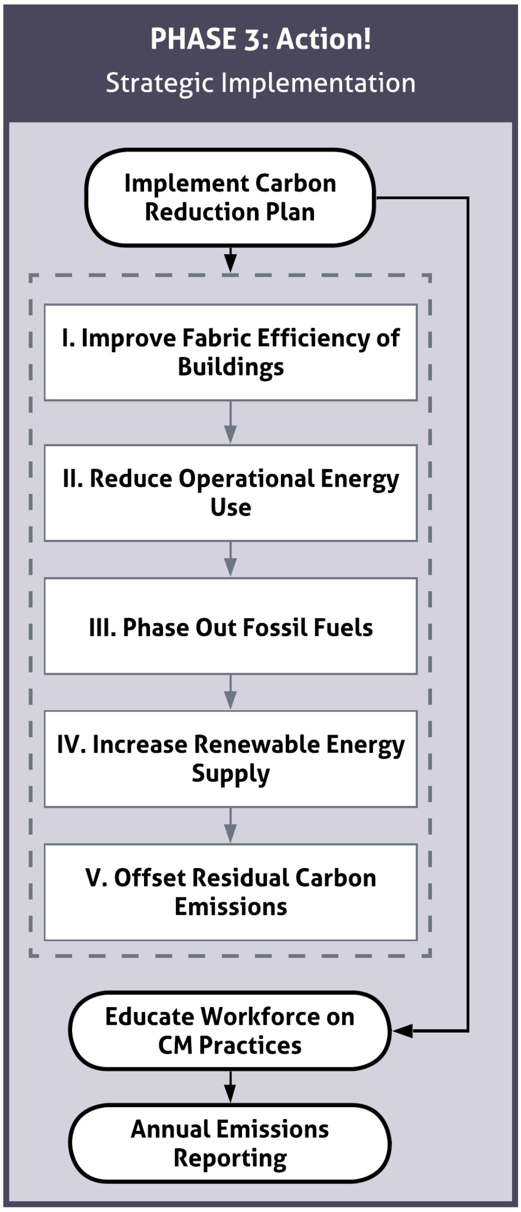


Figure 6-19. CMF-V3 - Phase 3: Action!

6.7 Chapter Summary

This Chapter focused on testing and validating the novel carbon management framework (CMF-V3) developed in this thesis. The case study, conducted with Knowsley Safari as the test site, was methodically designed to rigorously apply and assess each step of the CM framework. The study comprised two phases: a field study for validating the first phase of the framework and a desk-based study for developing a carbon reduction plan in line with the tasks of the framework's second phase.

6.7.1 Framework Validation

The field study was designed to gather energy consumption data to calculate Knowsley Safari's carbon footprint. This phase was successfully completed, meeting the desired objectives and confirming the effectiveness of the framework's first phase. Although certain limitations were identified, these were anticipated and provided valuable insights for potential modifications in future commercial applications of the framework.

The second phase involved developing a carbon reduction plan, resulting in a clear and actionable strategy created by the project stakeholders with the researcher's assistance. This phase successfully validated the framework's efficacy in creating a strategic plan for carbon reduction.

However, the third phase, focusing on strategic implementation, could not be validated due to time constraints and disruptions caused by COVID-19, leaving its effectiveness untested.

6.7.2 Revisiting the Framework Development Objectives

The case study set out a primary aim to test and validate the proposed carbon management framework and outlined four main objects:

- **To create a systematic process for carbon management aimed at net-zero operational carbon for SMEs.**

The researcher believes this objective was achieved through the design of CMF-V3. Through this testing procedure conducted throughout this Chapter, it was clear that the process defined in the framework was systematic and guided Knowsley Safari (a UK-based SME) to establish a carbon reduction plan.

- **Prioritising fabric and energy efficiency to minimise energy demand and associated emissions.**

As can be seen in Section 6.5.4, Figure 6-18 presents a decarbonisation roadmap for Knowsley Safari where carbon reduction measures follow the proposed hierarchy set out in Phase Three of CMF-V3 (refer to Figure 6-19) of taking a fabric-first approach to reducing emissions whilst aiming to reduce energy demand through modern technology and equipment upgrades substantially.

- **Creating an intuitive framework seamlessly integrated into a company's business model.**

As mentioned, it is unfortunate that phase three of the framework could not be validated during the case study described throughout this Chapter. However, the researcher has since spoken to the company. As of July 2023, Knowsley Safari aimed to pick up where it left off before the impacts of COVID-19 scuppered plans and forced the business to focus on its financial stability. The business plans to continue with the carbon reduction plan and, in the last few years, has made some changes to buildings and infrastructure based on the study's recommendations.

- **Focusing on educating employees and customers about carbon management, alongside implementing training for changes in standard operating procedures (SOPs).**

This is something that Knowsley Safari are passionate about, given their unique position as a business. A focus on education is inherent within the business model, and since this study, they have been sharing their carbon emissions journey with their employees.

6.7.3 Concluding Remarks

This leads us to conclude the results of this case study. While the study achieved most of its aims, limitations were encountered, and certain framework aspects remain unvalidated. The Chapter concludes that further development and testing are required for the framework's commercial application. The next Chapter will offer conclusions and recommendations for future work, building on the insights gained from this validation study.

CHAPTER 7

7. Conclusions

7.1 Chapter Overview

The concluding chapter of this thesis summarises the research findings, providing answers to the research questions set out in Chapter 3 and responding to the overarching objectives outlined in Chapter 1. This thesis followed the philosophical paradigm of pragmatism, taking a practical approach to framework development and applying a mixed-methods research design that followed the exploratory sequential: instrument development methodology. This approach, detailed in Chapter 3, provided a unique research project where academia and industry collaborated to establish a novel framework for carbon management within UK-based SMEs. The industry partner and sponsoring company, Knowsley Safari, provided the researcher with an exceptional opportunity to contribute original knowledge and ideas to a rapidly growing field. This chapter looks at the findings throughout each research stage, highlighting the limitations before recommending possible pathways for future work.

7.2 Research Findings

To begin with, a literature review was conducted to explore the knowledge and previous work completed on carbon management and was completed in two parts. A narrative literature review explored the history of climate policy and the development of carbon management as a field of its own, the review focussed on carbon management practices (CMPs) at a national and corporate level. This initial review assessed the following areas:

- The history of climate policy over the last four decades
- The UK's approach to climate policy
- The UK's contribution to climate change adaptation and mitigation
- Typical carbon management practices (CMPs) used at a national and corporate level.

Summarising the current state of research, there appears to be a limited focus on the relationship between small and medium-sized enterprises and carbon management, specifically within a UK setting. The evidence indicates a scarcity of practical applications reported in this field within the UK, with the majority of case studies occurring across parts of Asia. This observation suggests that UK-based SMEs might be receiving less attention than larger entities in the context of climate change adaptation and mitigation. This gap in research leads to the initial hypothesis that:

> ***A lack of academic research seems to exist when considering carbon management as a tool for climate change mitigation within UK-based SMEs.***

n an attempt to prove the hypothesis, a systematic review was conducted to provide a comprehensive analysis of the published literature, helping to identify any knowledge gaps. The systematic literature review, detailed in Section 2.6 and summarised in Table 7-1, was conducted in three distinct stages. Through this systematic approach, 57 articles were identified as relevant to the research focus, which is the ***exploration of the relationship between UK-based SMEs and Carbon Management.***

Upon identifying these relevant articles, the researcher conducted a review of this relationship. The review discussed vital aspects such as the drivers behind SMEs' involvement in carbon management, the typical barriers, and the methodologies deemed appropriate for carbon accounting in SME contexts. This thorough examination of the literature was instrumental in providing a clearer understanding of the current state of research in this area and the extent to which SMEs are considered in the broader narrative of carbon management and climate change mitigation.

Table 7-1. Summary of the Systematic Literature Search

Stage	Search Strategy	Results
1	Preliminary limited search of two databases to identify relevant keywords in title & abstract.	19 articles found
2	Comprehensive search of thirteen databases, using keywords identified from stage 1.	570 articles found (excluding duplicates) - 468 academic articles - 102 grey articles
3	Refinement and identification of articles that fit within the scope.	Extracted 116 articles that mentioned the relationship between principles of CM and SMEs in the *abstract.* Further refined to identify 57 articles that fit within the scope of research.

The study's results highlighted specific gaps in the knowledge and provided the motivations for the research conducted throughout this thesis. The systematic literature concluded by suggesting the following research questions to be answered throughout the research:

RQ 5. How do SMEs perceive energy and carbon management practices within their business, and to what level of knowledge do individual employees have in the fields of energy, carbon, and sustainability?

To answer this first question, a focus group study was set up to gather empirical evidence from industry employees, chosen based on their differing roles within SMEs. The focus group set out key themes in an interview schedule to guide discussions, taking a semi-structured approach to ensure all themes were covered. Findings from the study highlighted a critical central theme of "management" as an essential factor for SMEs when considering carbon management. Three meta-themes and eight sub-themes were identified, as shown in Table 7-2.

Table 7-2. Emerging Meta-themes & Sub-Themes from Focus Group Study

Meta-Theme	Sub-Themes
Strategic Management	Finance
	Sociology
	Environmental issues
Energy Management	Energy
	Carbon
Data Management	Framework concepts
	Instrument concepts
	Technology, software, and methodology

RQ 6. Can a generalised framework support UK-based SMEs in reducing their operational carbon impact, adapting techniques currently found at global, national and corporate level?

The second research question was explicitly focused on developing a framework and whether or not a generic framework could work for SMEs wanting to implement carbon management within their organisation. This question was answered through the research and development phase outlined in Chapter 5, where a novel systematic framework is proposed. The framework was developed based on existing techniques and methodologies, currently found at the corporate level, such as the Greenhouse Gas Protocol. Additionally, findings from the focus group study highlighted some key factors to consider when adapting existing corporate frameworks. They highlighted several potential challenges that might be faced when considering an SME.

The researcher soon realised that the scope of the framework was too broad, especially given that SMEs account for around 99.9% of all businesses in the UK and range from company's with one employee (e.g., sole traders) through to any business with up to 249 employees (UK Gov, 2022). To focus the development stage, it was decided that the intended target user would be narrowed to medium-sized organisations. The UK Government define a medium-sized organisation as having between 50-249 employees, which in 2022 accounted for approximately 35,000 businesses or 0.6% of the UK economy.

Despite still targeting businesses within the broader classification of SMEs, narrowing the focus toward this smaller group does place a level of uncertainty on whether or not the framework could apply to all SMEs, especially without further testing and validation.

RQ 7. Can a UK-based SME achieve net-zero operational emissions at net-zero cost?

Chapter 6 of the thesis focussed on the testing and validation procedures taken for the proposed framework; returning back to the philosophical approach for the research, a pragmatic approach was taken through a practical application to a UK medium-sized business. The business chosen for the study was research partner Knowsley Safari. Their site met all of the requirements for testing, and the strong collaboration meant immediate feedback was received. Identifying the framework's limitations and validating the theory behind the development phase. This question is slightly more challenging and requires further testing to validate fully.

The concept of net-zero carbon at net-zero cost depends on how it is defined. In the context of this research, it was defined as,

> *"The principle of net-zero emissions at net-zero cost is based on the holistic analysis of a business; considering its economic activities and environmental impact simultaneously, in order to identify cost neutral opportunities to reduce energy consumption and greenhouse gas emissions." - (Allas* et al.*, 2021)*

This means that, in theory, an SME can achieve net-zero operational carbon emissions at net-zero cost with careful and strategic planning for carbon reduction. By focusing on a fabric-first approach whilst considering low-cost energy conservation measures (e.g., increasing insulation levels and retrofitting LED lighting), a company can substantially reduce its energy demand, thus reducing operating costs, which would save the company money over time. Chapter 6 validates this theory through the use of a marginal abatement cost curve (or MACC), the MACC highlights the carbon reduction measures that demonstrate financial savings (over a specified assessment period) whilst also reducing emissions. Unfortunately, as previously mentioned, it is unsure whether this theory rings true, the concept of MACCs is well-established at a national and corporate level, but whether the same theory can be applied to a smaller organisation is yet to be found out.

RQ 8. Would the practice of carbon management in SMEs provide a great enough impact on national emissions to necessitate action from the UK Government?

To answer this question, it is essential to look at the scale of the problem. As previously mentioned, SMEs account for 99.9% of all businesses in the UK; in 2022, they accounted for circa 5.6 million businesses, compared to large organisations[1] with 7,655 organisations if we only considered several individual organisations. It would be blatantly apparent that the UK government should consider the impact of SMEs. However, let us look at the number of employees and revenue shown in Table 7-3, It is more balanced, and taking a fairly crude but useful estimate of the average turnover per business, large businesses are dominant here. This is the likely reason why the UK government has aimed all legislation toward large companies at this time and why academic research has thus far focussed on the carbon impacts of large corporate firms. Highlighted at the bottom of Table 7-3 with 50-249 employees are medium-sized enterprises, the intended target users for the instruments developed within this thesis. Given that medium-sized businesses have the second largest average turnover per business, it makes logical sense that they will be the next area of focus for the UK government, especially given the net-zero 2050 target set (Priestley, Hirst and Bolton, 2019).

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[1] ***Large company classification:*** *more than 250 employees or a turnover of more than €50 million or a balance sheet total more than €43 million*

Table 7-3. Estimated number of businesses in the UK private sector and their associated employment and turnover (UK Gov, 2022)

Business Size	No. of Businesses	Employment (thousands)	Turnover (millions)	Average Turnover per Business
All businesses	5,590,900	27,054	4,156,773	£74,349
Large Company (≥ 250 employees)	7,655	10,622	2,032,334	£26,549,105
SMEs (0-249 employees)	5,583,245	16,432	2,124,439	£38,050
No employees	4,174,920	4,399	277,599	£6,649
1-9 employees	1,162,155	4,308	530,456	£45,644
10-49 employees	210,550	4,228	608,852	£289,172
50-249 employees	35,620	3,497	707,532	£1,986,334

To directly answer the research question is challenging; however, given the evidence presented here, it is likely that SMEs, as a collective, do provide a significant enough impact on national emissions to necessitate action from the UK government. However, they will likely take a phased approach, with medium-sized organisations as the next target.

7.3 Research Limitations

The methodology taken for this research had some inherent limitations, some realised throughout this study, and others are discussed here:

The research design chosen for phase one involved conducting a focus group. By design, focus groups are challenging to organise and control; they encourage participants to have semi-structured discussions on a topic that the researcher has introduced; however, these discussions can often wander off course, with participants wanting to talk around issues unrelated to the original topic.

This can prove difficult when analysing focus group transcripts and conflicting views can cause ambiguity. A limited number of participants are included for each session; for the case of the research within this thesis, six participants contributed to one focus group meeting. This is a relatively small sample to obtain all the information required. During the analysis stage, it became clear that specific questions needed to be discussed, with some controversy among the participants creating a challenge when attempting to identify and conclude themes.

By only conducting one focus group study, a limitation was reached when attempting to validate the findings.

As previously mentioned, there was a level of ambiguity in some of the discussions, by holding a secondary focus group with the same participants, some key themes could be validated. Unfortunately, a second focus group was not possible, given the time available to complete the rest of the research study.

The research initially set out to establish a carbon management framework for all UK-based SMEs. However, it was soon realised that this would be challenging given the scale and magnitude of SMEs in the UK (refer to Table 7-3 for context). n the end, it was decided to narrow the focus of the research towards medium-sized organisations. This leads to the limitations of the research partner. Given that the research partner was also part-funding the research, there was a certain level of expectation to deliver a research project that would directly benefit the company. This is not a massive problem as the company in question was, in fact, a UK-based SME; however, it did mean that the instruments developed were only tested on one company at one location. This became an issue when attempting to validate the instruments, whilst a comprehensive testing and validation study was conducted, by testing only on a single company, there is only one group of stakeholders that can provide feedback. Furthermore, the framework was designed to function for the research partner, and their employees contributed to some of the initial ideas during the focus group, meaning that bias has to be considered. The operations of the research partner were diverse and covered a range of sectors, however, without further testing on a number of other companies, it is challenging to fully validate the criteria set out (testing for functionality, compatibility, and usability).

Finally, methodological limitations must be considered. Combining qualitative and quantitative data with mixed-method research has several inherent limitations. The first was the quantity and complexity of collecting and analysing two types of data; this required careful planning to ensure that two studies could be conducted within the time period allowed. Time constraints are often seen as a major limitation when being conducted as part of a postgraduate degree (Ashley *et al.*, 2019), especially when considering sequential projects. This research followed the exploratory sequential: instrument development method, where qualitative data collection and analysis is followed by a period of instrument development, before running a quantitative study to test and validate. This feeds into previously discussed limitations around the lack of available time to comprehensively validate all elements of the research. In addition, the large volume of data generated through a mixed-methods approach created resource challenges during the analysis phase. A further limitation of the sequential method is that findings are presented in separate studies; if these studies are well linked in a succinct story, then the benefit of this method is recovered to the reader (Ashley *et al.*, 2019).

The thesis draws its conclusions solely from collaboration with one company. Although the researcher has extensively considered the factor of bias within the studies presented, there will always naturally be a degree of bias within the outputs presented. The research limitations are discussed in this chapter and lead to several final conclusions and ideas for potential future research. Fundamentally, the researcher believes that the key aim and objectives set out for this research have been achieved; a novel framework is presented for the integration of carbon management practices within UK-based medium-sized companies, additionally, supporting instrumentation in the form of a questionnaire surveying tool and a statistical analysis model were developed to work alongside the framework as a complete and robust package. The research outputs presented are a first attempt at addressing the underlying issues faced when considering the impact of SMEs on the climate and offer an alternative methodology to encourage more companies to incorporate climate change adaptation and mitigation as core business practices.

7.4 Concluding Remarks & Research Contribution

Throughout this research, the primary aim, as set out in Chapter 1 and following the thesis title, was **to pragmatically develop a carbon management framework for UK SMEs**. Through the mixed method design approach taken, the researcher has conducted investigative research through a review of the literature followed by a focus group study. This investigative phase was designed to provide the researcher with as much information as possible to understand the workings of a UK SME. It was soon realised that, by definition, small and medium-sized enterprises pose a vast array of business types and sizes. The fact that SMEs account for 99.9% of all businesses in the UK tells a story on its own. At this point, the researcher realised that creating a "one-size fits all" framework for this many businesses would prove extremely challenging.

However, there was a solution to this conundrum. This research has been lucky to be partly funded by an industrial partner, Knowsley Safari, who happened to be a UK-based SME. The researcher realised what an opportunity this would provide, and this is when the decision to limit the research scope was made. Knowsley Safari is classified as a medium-sized business employing between 50 and 249 staff on a unique site that is so diverse in its operation that it can emulate a wide variety of business types. This realisation became the golden ticket to developing the carbon management framework.

With Knowsley Safari and its diverse operations chosen as the overarching case study, the researcher had a more focused approach that provided an opportunity for future generalisations. This collaboration between the University and an industrial partner provides a considerable novelty to the research. The specific approach conducted throughout this thesis is unique as a result and contributes a rich pool of knowledge to the field of carbon management.

The Carbon Management Framework (CMF-V3) developed throughout this thesis is not without its limitations (as discussed throughout various chapters and summarised in Section 7.3); however, the researcher believes that the aim and objectives set out at the start of this thesis have been thoroughly achieved.

A novel carbon management framework was created and targeted toward medium-sized organisations operating in the UK. A pragmatic approach was taken through collaboration with the research industrial partner, who contributed knowledge and experience to development and testing, allowing the theoretical research to be applied in a real-world setting. The researcher believes this element is fundamental to justifying the novelty of the research and the success of the framework proposed in this thesis.

Despite that, the researcher acknowledges that this work has only laid the groundwork for a novel approach that could impact UK carbon emissions reductions.

7.5 Suggestions for Future Work

That said, the researcher suggests several ideas for future work to build upon the research presented within this thesis. First and foremost, the carbon management instruments presented throughout this thesis provide a solid grounding for further development. However, one of the significant limitations was the application to only one company. Ideally, the framework would be applied to several SMEs of varying sizes operating in various sectors.

During the preliminary investigation, ideas and themes were generated based on six employees' discussions in the form of a focus group. Conducting several focus groups with similar participants from varying organisations would be interesting to compare the findings and emerging themes. This could generate a series of ideas for future adaptations of the original research conducted in this thesis.

The research set out to create a generic framework for all UK-based SMEs; ultimately, this was narrowed to focus on UK-based medium-sized businesses. Two potential avenues could be explored here; firstly, the applicability and suitability to smaller businesses would provide some interesting findings. Secondly, it would be intriguing to explore the repeatability of this study in other countries and whether the common challenges SMEs face are comparable.

This thesis lays the foundations for what could be a newly adopted methodology for SMEs in the near future, especially given the trend in legislation and mandatory reporting. In January of 2023, as part of 'The European Green Deal', the European Commission announced new rules on sustainability reporting for businesses operating within the European Union (EU). The Corporate Sustainability Reporting Directive (CSRD) aims to "modernise and strengthen the rules around social and environmental reporting." the directive includes rules around mandatory carbon accounting and reporting (including scope 1, scope 2, and, where relevant, scope 3 emissions) (European Parliament, 2022). Whilst the directive will initially focus on large companies from 2025, by 2027, the compliance requirements will be expanded to include listed SMEs. This legislation is the first time SMEs will be mandated to report on sustainability issues, and this trend will likely continue as the world attempts to adapt and mitigate against the impacts of anthropogenic climate change.

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Appendices

Appendix A – Systematic Literature Review

Appendix A1. SLR Record

Search Results

Stage 1 – Scoping Study

Title

< "small and medium sized enterprises" OR "SME" OR "SMEs" OR "small business" OR "small companies" OR "small company" OR "small enterprise" OR "medium enterprise" >

AND

Abstract

< "carbon management" OR "climate policy" OR "carbon accounting" OR "carbon emissions" >

Environment Complete

Articles Found

ID	Title	Citation	Keywords
EC1	**Benefits and challenges of streamlined life-cycle assessment for SMEs – findings from case studies on climate change impacts.**	**(Niemistö et al., 2019)**	**carbon footprint** **climate change** **eco-design** **Life cycle assessment** **life cycle thinking** **small and medium-sized enterprises**
EC2	**Carbon footprint analysis as a tool for energy and environmental management in small and medium-sized enterprises.**	**(Giama and Papadopoulos, 2018)**	**Carbon footprint analysis** **energy management** **small and medium enterprises** **sustainability**

EC3	**Remanufacturing as a means for achieving low-carbon SMEs in Indonesia.**	**(Fatimah and Biswas, 2016)**	**Greenhouse gas** **Life cycle assessment** **Small- and medium-sized enterprise**
EC4	**More than half of China's CO2 emissions are from micro, small and medium-sized enterprises.**	**(Meng et al., 2018)**	**Carbon intensity** **Climate change** **CO2 emissions** **Firm heterogeneity** **SMEs** **Supply chain**
EC5	**Why & how energy efficiency policy should address SMEs.**	**(Fawcett and Hampton, 2020)**	**Energy efficiency** **EU** **Organisations** **Policy** **SMEs** **UK**
EC6	**Products, practices and processes: exploring the innovation potential for low-carbon housing refurbishment among small and medium-sized enterprises (SMEs) in the UK construction industry.**	**(Killip, 2013)**	**Housing refurbishment** **Industry practice** **Low-carbon**
EC7	**Energy Performance Contract models for the diffusion of green-manufacturing technologies in China: A stakeholder analysis from SMEs' perspective.**	**(Liu et al., 2017)**	**Energy performance contracting** **Energy-saving technology** **Green-manufacturing** **Small-and-medium size enterprises** **Stakeholder theory** **Trade-offs**
EC8	**Environmental management in the aspect of sustainable development in micro-, small-, and medium-sized enterprises.**	**(Wielgórka, 2016)**	**Corporate social responsibility (CSR)** **MMSP** **Sustainable development economy**

EC9	**Increasing participation in climate policy implementation: a case for engaging SMEs from the transport sector in the city of São Paulo.**	**(Setzer and Biderman, 2013)**	**climate change** **multilevel governance** **participation** **small and medium-sized enterprises**
EC10	**Exploring drivers for energy efficiency within small- and medium-sized enterprises: First evidences from Italian manufacturing enterprises**	**(Cagno and Trianni, 2013)**	**Drivers** **Industrial energy efficiency** **Small and medium-sized enterprises**
EC11	**A review of interventions to encourage SMEs to make environmental improvements.**	**(Parker, Redmond and Simpson, 2009)**	***Environmental law** ***Pollution** ***Carbon dioxide** ***Emissions (Air pollution)** ***Air pollution** ***Air pollution monitoring** **Small business** **Intervention (Federal government)** **International economic relations**
EC12	**Being green and export intensity of SMEs: The moderating influence of perceived uncertainty**	**(Martin-Tapia, Aragon-Correa and Senise-Barrio, 2008)**	**Natural environment** **Proactive environmental strategies** **Small firms** **Uncertainty**

Business Source Complete

Articles Found

ID	**Title**	**Citation**	**Keywords**
BC1	**How to reduce carbon emissions of small and medium enterprises (SMEs) by knowledge sharing in China.**	**(Yao, Huang and Song, 2019)**	**Cap-and-trade** **knowledge sharing** **small and medium enterprises**

BC2	Barriers and motivators to the adoption of energy savings measures for small- and medium-sized enterprises (SMEs): the case of the ClimateSmart Business Cluster program.	(Meath, Linnenluecke and Griffiths, 2016)	Energy efficiency Government program Small and medium size enterprises, (SMEs)
BC3	EU Emissions Trading: Distinctive Behavior of Small Companies.	(Naegele and Zaklan, 2016)	EU ETS offsets participation transactions cost
BC4	Impact analysis of the implementation of cleaner production for achieving the low-carbon transition for SMEs in the Inner Mongolian coal industry.	(Zhou and Zhao, 2016)	Cleaner production CO 2 emission reduction IPAT equation TRIZ
BC5	Being green and export intensity of SMEs: The moderating influence of perceived uncertainty	(Martin-Tapia, Aragon-Correa and Senise-Barrio, 2008)	Natural environment Proactive environmental strategies Small firms Uncertainty
BC6	GREY LITERATURE Put a Price on Carbon to Help Small Business.	(Lynch, 2010)	*Small business Climate change laws Energy consumption & climate Energy industry laws Emission control
BC7	GREY LITERATURE Small Business Catches the Green Bug.	(Scott, 2007)	*Consumers *Green marketing Green products Climate change

Stage 2 – Main Search

Environment Complete

Database	**Environment Complete**
Date of search	**15/10/19**
Version of database	**Environment Complete**
Interface used	**EBSCOhost**
Number of Refs. found	**64**
Search terms used	***AB*** **("carbon * management" OR "carbon accounting" OR "carbon footprint*" OR "carbon * reduction" OR "carbon * abatement" OR "low carbon" OR "zero carbon")**
	AND *AB* ("small * medium * enterprises" OR "SME" OR “SMEs” OR "small business*" OR "small compan*" OR "small enterprise*" OR "medium business*" OR "medium compan*" OR "medium enterprise*")
	NOT *AB* (biodiesel* OR soil*)
	OR *TX* (("carbon * management" OR "carbon * reduction framework" OR "* carbon framework" OR "carbon * method*"))
	AND *TX* ("small * medium * enterprises" OR “SMEs”)
	NOT *AB* (biodiesel* OR soil*)
Limiters	**Full-Text Online ; Published between ‘Jan 1995 – present’ ; Academic Journal**
Expanders	**Apply related words ; Apply equivalent subjects**
Complementary search activities	**Grey Literature searched: 3 articles found**
Reference manager	**Mendeley**

Business Source

Database	**Business Source**
Date of search	**15/10/19**
Version of database	**Business Source Complete**
Interface used	**EBSCOhost**

Number of Refs. found	**87**
Search terms used	***AB*** **("carbon * management" OR "carbon accounting" OR "carbon footprint*" OR "carbon * reduction" OR "carbon * abatement" OR "low carbon" OR "zero carbon")**
	AND ***AB*** **("small * medium * enterprises" OR "SME" OR "SMEs" OR "small business*" OR "small compan*" OR "small enterprise*" OR "medium business*" OR "medium compan*" OR "medium enterprise*")**
	OR ***TX*** **("carbon management" OR "carbon * reduction framework" OR "* carbon framework" OR "carbon * method*")**
	AND ***TX*** **("small * medium * enterprises" OR "SMEs")**
Limiters	**Full-Text Online; Published between 'Jan 1995 – present'; Academic Journal; Language: English**
Expanders	**Apply related words**
Complementary search activities	**Grey Literature searched: 73 articles found**
Reference manager	**Mendeley**

Sage Business Cases

Database	**Sage Publications**
Date of search	**16/10/19**
Version of database	**Sage Publications**
Interface used	**Sage Knowledge**
Number of Refs. found	**16**
Search terms used	***FULL TEXT*** **("Zero carbon")**
	OR ***Abstract*** **(carbon OR Sustainability OR Energy)**
	AND ***Abstract*** **(Small)**
Limiters	**n/a**
Expanders	**n/a**
Complementary search activities	**n/a**
Reference manager	**Mendeley**

Science Direct

Database	**Science Direct**
Date of search	**16/10/19**
Version of database	**Science Direct**
Interface used	**Science Direct**
Number of Refs. found	**56**
Search terms used	***AB*** **("carbon management" OR "energy efficiency measure" OR "carbon footprint" OR "energy management") AND ("small medium enterprises" OR "SME" OR "small business" OR "small enterprise" OR "small company")**
Limiters	**Full-Text Online; Published between 'Jan 1995 – present'; Academic Journal; Language: English**
Expanders	**Apply related words**
Complementary search activities	**n/a**
Reference manager	**Mendeley**

Scopus

Database	**Scopus**
Date of search	**18/10/19**
Version of database	**Scopus**
Interface used	**Scopus**
Number of Refs. found	**40**
Search terms used	***(TITLE-ABS-KEY (("carbon management" OR "carbon footprint" OR "Zero Carbon" OR "carbon accounting")) AND TITLE-ABS-KEY (("small medium enterprises" OR "SMEs" OR "small business" OR "small enterprise" OR "small company")))***
Limiters	**Full-Text Online; Published between 'Jan 1995 – present'; Academic Journal; Language: English**
Expanders	**Apply related words**

Complementary search activities	**Grey Literature Searched: 24 refs found**
Reference manager	**Mendeley**

Web of Science

Database	Web of Science
Date of search	18/10/19
Version of database	Web of Science Collection
Interface used	Web of Knowledge
Number of Refs. found	20
Search terms used	*TOPIC: ("carbon management" OR "carbon footprint" OR "Zero Carbon" OR "carbon accounting") AND TOPIC: ("small medium enterprises" OR "SMEs" OR "small business" OR "small enterprise" OR "small company")*
Limiters	Full-Text Online; Published between 'Jan 1995 – present'; Academic Journal; Language: English
Expanders	Apply related words
Complementary search activities	Grey Literature Searched: 6 refs found
Reference manager	Mendeley

Google Scholar

Database	**Google**
Date of search	**18/10/19**
Version of database	**Google Scholar**
Interface used	**Google**

Number of Refs. found	**99**
Search terms used	***("carbon management" OR "carbon footprint" OR "Zero Carbon" OR "carbon accounting") AND ("small medium enterprises" OR "SMEs" OR "small business" OR "small enterprise" OR "small company")***
Limiters	**Full-Text Online; Published between 'Jan 1995 – present'; Academic Journal; Language: English**
Expanders	**Apply related words**
Complementary search activities	**N/A**
Reference manager	**Mendeley**

e-Books (EBSCO)

Database	e-Books EBSCO
Date of search	18/10/19
Version of database	eBook Collection
Interface used	EBSCO
Number of Refs. found	46
Search terms used	TX ("carbon management" OR "carbon footprint" OR "Zero Carbon" OR "carbon accounting") AND TX ("small medium enterprises" OR "SMEs" OR "small business" OR "small enterprise" OR "small company")
Limiters	Full-Text Online; Published between 'Jan 1995 – present'; Academic Journal; Language: English
Expanders	Apply related words
Complementary search activities	N/A
Reference manager	Mendeley

eThOS

Database	eThOS
Date of search	18/10/19
Version of database	eThOS
Interface used	eThOS
Number of Refs. found	18
Search terms used	Any word:("carbon management" OR "Zero Carbon" OR "carbon accounting" OR “carbon emission”) AND Any word:("small medium enterprises" OR "SMEs" OR "small business" OR "small enterprise" OR "small company")
Limiters	Full-Text Online; Published between ‘Jan 1995 – present’; Academic Journal; Language: English
Expanders	Apply related words
Complementary search activities	N/A
Reference manager	Mendeley

OATD

Database	Open Access Theses and Dissertations
Date of search	18/10/19
Version of database	OATD
Interface used	OATD
Number of Refs. found	11

Search terms used	abstract:(emissions OR "carbon footprint" OR "carbon accounting" OR "carbon management") AND abstract:("small medium enterprises" OR SMEs OR "small business" OR "small enterprise" OR "small company")
Limiters	Full-Text Online; Published between 'Jan 1995 – present'; Academic Journal; Language: English
Expanders	Apply related words
Complementary search activities	N/A
Reference manager	Mendeley

University of Liverpool Library

Database	University of Liverpool Library
Date of search	18/10/19
Version of database	-
Interface used	EBSCO Host
Number of Refs. found	19
Search terms used	AB "carbon management" AND AB (smes OR "small and medium sized enterprises" OR "small businesses" OR "small companies") OR TI ("carbon accounting" OR "zero carbon" OR "low carbon") AND (smes or small and medium sized enterprises or small businesses or small companies)
Limiters	Full-Text Online; Published between 'Jan 1995 – present'; Academic Journal; Language: English
Expanders	Apply related words

Complementary search activities	N/A
Reference manager	Mendeley

Appendix B – Focus Group

Appendix B1. Participant Information Sheet

1. Version Number and Date: V1, 08/03/2018

You are being invited to participate in a research study. Before you decide whether to participate, it is important for you to understand why the research is being done and what it will involve. Please take time to read the following information carefully and feel free to ask us if you would like more information or if there is anything that you do not understand. We would like to stress that you do not have to accept this invitation and should only agree to take part if you want to.

Thank you for reading this

2. What is the purpose of the study?

The purpose of this research is to develop a framework for carbon abatement and mitigation for commercial entities that classify as small and medium-sized enterprises (SMEs). The researcher believes that there are significant areas of carbon reduction methodologies that are yet to be dealt with, in particular when addressing SMEs in the UK. Addressing this problem is the main focus of the research and the main driver for the development of a novel, holistic set of carbon management (CM) instruments. The instruments aim to address the key issues that UK SMEs currently face when attempting to tackle their operational carbon impact. The purpose of the focus group study is to gather information through a series of semi-structures discussions. The researcher will ask participants to discuss ideas they may have for a new set of instruments that will provide SMEs with a roadmap to reducing their carbon emissions. Questions will be asked to the participants to discover their opinion on the following topics,

- Operational energy use
- Energy efficiency
- Climate related issues
- Typical resources of an SME
- Business priorities for SMEs
- Sustainability
- Environmental Concerns

The outputs and findings from this study will provide the researcher with a number of key themes to investigate further. Following further investigation, a series of carbon reduction instruments will be developed specifically designed with small and medium enterprises as the primary focus. The instruments will then be tested on a case study to verify functionality and validate the instruments.

3. Why have I been chosen to take part?

You are being approached as part of a research study that aims to develop a set of novel carbon abatement and mitigation instruments for SMEs.

4. Do I have to take part?

Participation in this study is voluntary and you have the right to decline to take part. If you decide to withdraw from participating at any point, you may do so freely without explanation.

5. What will happen if I take part?

If you decide to take part, you will be asked questions about your company operations and typical energy consumption, as well as specific questions relating to instrument development.

Upon written consent, the **focus group transcript** will be posted to you by email, in person or it will be posted to you by postal-mail if required. The focus group should take between **1 hr to 2 hrs** to complete.

6. How will my data be used?

The University processes personal data as part of its research and teaching activities in accordance with the lawful basis of 'public task', and in accordance with the University's purpose of "advancing education, learning and research for the public benefit".

Under UK data protection legislation, the University acts as the Data Controller for personal data collected as part of the University's research. The principal investigator/researcher acts as the Data Processor for this study, and any queries relating to the handling of your personal data can be sent to [**Tom Johnston, t.johnston2@liverpool.ac.uk**].

Further information on how your data will be used can be found in the table below.

How will my data be collected?	**By means of a written questionnaire**
How will my data be stored?	**On the University of Liverpool's digital data storage, which will be accessible only by authorised principal investigator and protected with username and password.**
How long will my data be stored for?	**10 years until December 2028**
What measures are in place to protect the security and confidentiality of my data?	**The data will be stored on the researcher and supervisor's M-drive(s), a digital drive for the University of Liverpool, and protected by username and password.** **In the case personal information is accidentally released, this will be anonymised by striking through participants' names with black ink from hard copies of forms, or deleting them from electronic versions and omitting them in the transcripts.**
Will my data be anonymised?	**If requested in the Consent Form, otherwise not.**
How will my data be used?	**By the researcher and their supervisor in writing the researcher's thesis and**

	potentially in research continuing from that work, such as conference proceedings and/or journal articles.
Who will have access to my data?	**Data will be accessed only by project members (researcher and supervisor).**
Will my data be archived for use in other research projects in the future?	**The raw data will be stored on the University of Liverpool researchers' M drive and protected by a username and password. The outputs of this research including dissertation, journal articles, conference papers or other publications will be accessed by academics and the public.**
How will my data be destroyed?	**Other than what is incorporated in the thesis and other published research outputs, the data will be erased after 10 years of participation. Audio data, interview transcripts, imaging data and raw video data will be destroyed from all electronic storage devices, by means of formatting from portable devices and deleting from the digital data storage, after 10 years from your participation.**

7. Anonymity.

It is not the intention of this study to collect any personal information about you. By default, data will in fact be anonymised, i.e. identifying information will be replaced by a pseudonym or code such as Subject 1, Subject 2, etc.

8. Expenses and / or payments

No expenses or payments can be made for this participation

9. Are there any risks in taking part?

We do not foresee any risks in taking part.

10. Are there any benefits in taking part?

A greater understanding of the subject will be provided upon completion of this project and a digital/electronic copy of the research thesis will be sent to you upon your request.

11. What will happen to the results of the study?

The results will form part of the research thesis and academic publications such as conference proceedings and/or journal articles.

12. What will happen if I want to stop taking part?

You can withdraw from the study at any point. Results up to the point of withdrawal may be used if you agree and after your consent. Otherwise, you may request that your data are destroyed by contacting the researcher, Tom Johnston, **within 6 weeks after participation.** After this time all data will be anonymised, so it will not be possible to remove your answers.

13. What if I am unhappy or if there is a problem?

If you are unhappy or there is any problem, please speak to the researcher, Tom Johnston

If you remain unhappy or have a complaint, please contact the Research Ethics and Integrity Office at ethics@liv.ac.uk or +44 (0)151 748739, providing details of the study. If you have concerns about the way in which the University processes your personal data, you can lodge a complaint with the Information Commissioner's Office by calling +44 (0)303 123 1113.

14. Who can I contact if I have further questions?

Principal Investigator

Tom Johnston

t.johnston2@liverpool.ac.uk

University of Liverpool, School of Architecture

Supervisor

Dr. Stephen Finnegan

sfinn@liverpool.ac.uk

University of Liverpool, School of Architecture

I can confirm that I have read and agree to the above information

Participant Name……………………………………………………………………………………………

Signature ……………………………………………………………………………………………..

Date (dd/mm/yyyy)………………………………………………………………………………………….

Appendix B2 – Participant Consent Form

Version number & date:	V2, 08/03/2018
Research ethics approval number:	**7696**
Title of the research project:	**Development of a framework to assist SMEs engage in carbon reduction programmes**
Name of researcher:	**Tom Johnston**

#	**Consent Form**	**Please Initial ▼**
1	**I confirm that I have read and understood the Information Sheet dated [08/03/2018] for the above study and had questions answered satisfactorily.**	
2	**I understand that my participation is voluntary and that I am free to stop taking part and can withdraw from the study at any time without giving any reason and without my rights being affected. In addition, I understand that I am free to decline to answer any particular question or questions.**	
3	**I understand that taking part in this study involves an audio recorded group interview with supplementary hand-written notes. I consent to your use of quotations from my statements for academic purposes such as research dissertation, conference proceedings and journal articles.**	
4	**I understand that my personal data will NOT BE linked to these quotations**	
5	**I understand that I can ask for access to the information I provide and I can request the destruction of that information if I wish within 6 weeks after participation. I understand that following this period I will no longer be able to request access to or withdrawal of the information I provide.**	
6	**I understand that the information I provide will be held securely and in line with data protection requirements at the University of Liverpool until it is fully anonymised and then deposited in the archive for sharing and use by other authorised researchers to support other research in the future.**	
7	**I understand that the resulting dissertation will be deposited in the University Library for sharing and use by other scholars.**	
8	**I understand that any further research outputs (e.g. journal articles, conference proceedings, research documentary) will be publicly available to other scholars and/or the general public.**	
9	**I understand that a transcript of my interview will be stored and retained for in digital data storage within the University of Liverpool and protected by username and password, which will be accessible only by authorised researchers for 10 years.**	

10	**Please tick this box if you would like a digital / electronic copy of the dissertation to be sent to you after completion.**	
11	**I understand that my responses will be kept strictly confidential. I give permission for members of the research team to have access to my fully anonymised responses. I understand that my name will not be linked with the research materials, and I will not be identified or identifiable in the report or reports that result from the research.**	
12	**I agree to take part in the above study.**	

Participant name Date Signature

Principal Investigator

Tom Johnston

University of Liverpool

School of Architecture

t.johnston2@liverpool.ac.uk

Supervisor

Dr. Stephen Finnegan

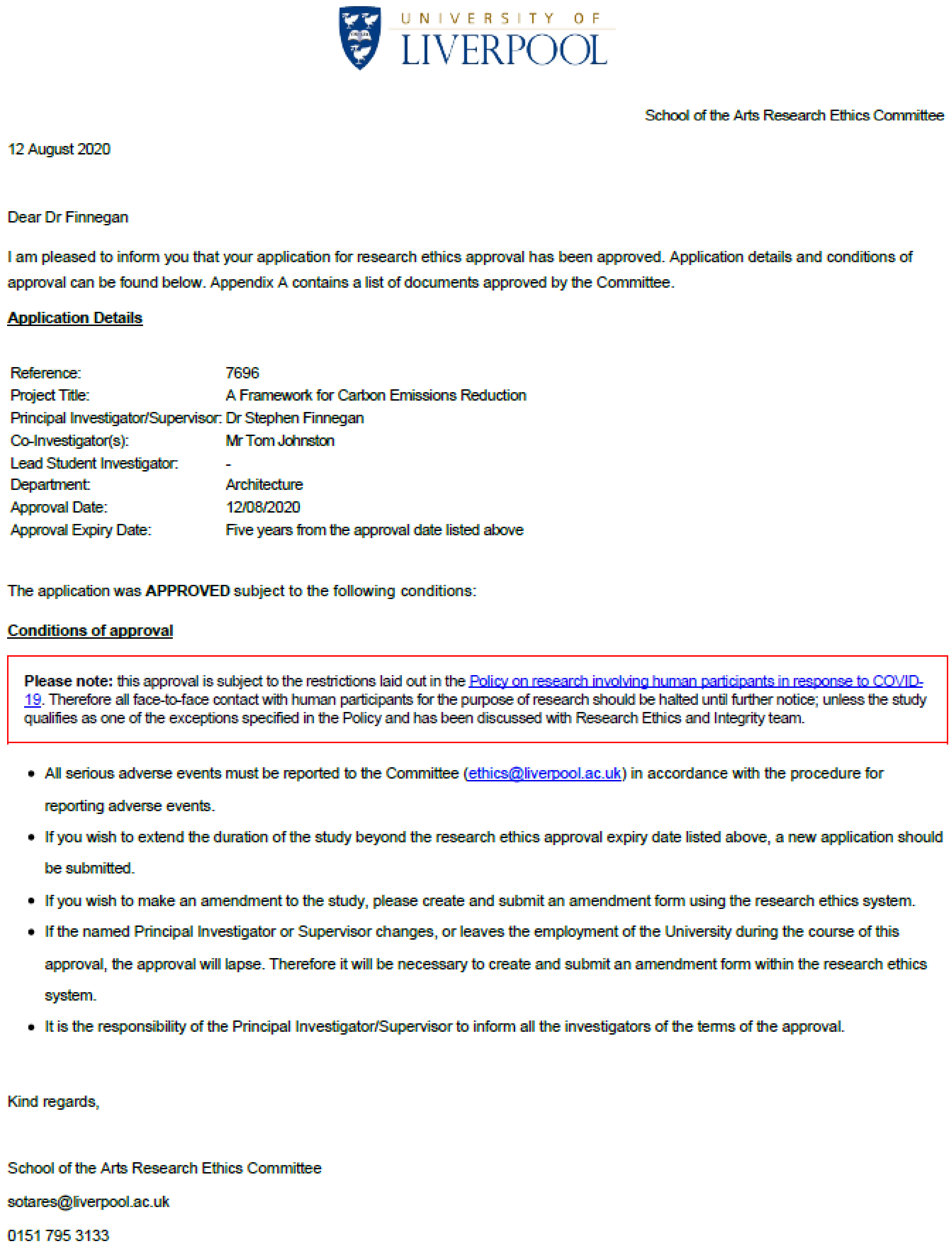
University of Liverpool

School of Architecture

sfinn@liverpool.ac.uk

Appendix B – Focus Group

Appendix B3 – Ethics Approval Letter



UNIVERSITY OF LIVERPOOL

School of the Arts Research Ethics Committee

12 August 2020

Dear Dr Finnegan

I am pleased to inform you that your application for research ethics approval has been approved. Application details and conditions of approval can be found below. Appendix A contains a list of documents approved by the Committee.

Application Details

Reference:	7696
Project Title:	A Framework for Carbon Emissions Reduction
Principal Investigator/Supervisor:	Dr Stephen Finnegan
Co-Investigator(s):	Mr Tom Johnston
Lead Student Investigator:	-
Department:	Architecture
Approval Date:	12/08/2020
Approval Expiry Date:	Five years from the approval date listed above

The application was **APPROVED** subject to the following conditions:

Conditions of approval

Please note: this approval is subject to the restrictions laid out in the Policy on research involving human participants in response to COVID-19. Therefore all face-to-face contact with human participants for the purpose of research should be halted until further notice; unless the study qualifies as one of the exceptions specified in the Policy and has been discussed with Research Ethics and Integrity team.

- All serious adverse events must be reported to the Committee (ethics@liverpool.ac.uk) in accordance with the procedure for reporting adverse events.
- If you wish to extend the duration of the study beyond the research ethics approval expiry date listed above, a new application should be submitted.
- If you wish to make an amendment to the study, please create and submit an amendment form using the research ethics system.
- If the named Principal Investigator or Supervisor changes, or leaves the employment of the University during the course of this approval, the approval will lapse. Therefore it will be necessary to create and submit an amendment form within the research ethics system.
- It is the responsibility of the Principal Investigator/Supervisor to inform all the investigators of the terms of the approval.

Kind regards,

School of the Arts Research Ethics Committee

sotares@liverpool.ac.uk

0151 795 3133

Appendix B4 – Study Schedule – For Ethics Approval Only -

Introduction

a. Introduce self to participants and explain the purpose of the study and why they have been invited to take place
b. Explain the topics that will be discussed:
   - Operational energy use
   - Energy efficiency
   - Climate related issues
   - Typical resources of an SME
   - Business priorities for SMEs
   - Sustainability
   - Environmental Concerns
c. Explain what the data is being used for and how it will be used
d. Describe privacy and confidentiality of data. At this point assign letters to participants and state the importance of not using any names during the study.

Environmental Issues

a. What are you opinions on the state of the environment and how much are you aware of climate-related issues?
b. How important do you think it is to consider reducing carbon emissions in the industry?
c. Do you know what is meant by a carbon footprint?
d. Encourage discussion on climate change and the environment

Energy

a. How seriously do SMEs consider their energy use?
b. How much do you know about the energy efficiency measures?
c. How much do you know about Low Carbon Technology and Renewable energy?
d. How do your respective companies monitor operational energy?
e. How do your respective companies manage its energy use?
f. How does an SME cope with regular increases in energy prices?

Resources

a. Are there any specific roles or departments that consider energy consumption?

b. Are there any specific roles or departments that consider sustainability?
c. What portion of allocated budget, if any, is used for sustainability and environmental projects?
d. Do you think a typical SME has the time and resources to learn how to adopt to a new procedure?
e. Encourage discussion on company resources

Drivers & Barriers

a. When undertaking a new business venture or project what are the main drivers?
b. What are the typical barriers faced during new ventures as an SME?
c. Is there any pressure for SMEs to consider their environmental impact?
d. Are you aware of any government legislation encouraging and/or enforcing SMEs to report on their carbon emissions?

Tools & Techniques

a. Are you aware of any documents, protocols, or tools available for businesses to help reduce their carbon footprint?
b. What do you think are the main attributes that would encourage an SME to use carbon reduction tools and procedures?
c. What are the main considerations for SMEs when undertaking a new project or venture?
d. Do your respective companies use forecasting techniques for any business-related activities?

Software

a. What software do your respective companies use to control projects?
b. How does the business manage its finances? And What software is used to do this?
c. Do your respective companies use Microsoft software? If yes, please state specific software and what is it used for?

Limitations

a. What do you think are the main limitations for SMEs wanting to undertake a carbon reduction project?
b. What do you think would deter an SME from using a newly developed set of instruments?

Conclusion

a. Reiterate how the information will be used.
b. Thank participants and close the focus group study.

Appendix C – Instrument Development – Materiality Assessment

Appendix C1 – Materiality Assessment

Appendix Table 1. Materiality Assessment Questions

Question 1	How important is the type of electricity consumed when considering the following KPIs?
Question 2	**How important is energy monitoring & reporting when considering the following KPIs?**
Question 3	**How important is the cost of energy when considering the following KPIs?**
Question 4	**How important is the efficiency of equipment & machinery when considering the following KPIs?**
Question 5	**How important is the thermal performance of buildings occupied when considering the following KPIs?**
Question 6	**How important is the frequency of maintenance to buildings & infrastructure when considering the following KPIs?**
Question 7	**How important is the environmental impact of the goods or services sold by a business when considering the following KPIs?**
Question 8	**How important is it to consider the sustainability credentials of your supply chain partners when considering the following KPIs?**
Question 9	**How important is the quantity and frequency of goods procured when considering the following KPIs?**
Question 10	**How important is it to account and report on operational carbon emissions when considering the following KPIs?**
Question 11	**How important is it to account and report on value chain emissions when considering the following KPIs?**
Question 12	**How important is the concept of 'Net-Zero Carbon' when considering the following KPIs?**
Question 13	**How important is it to train and educate employees when implementing a new policy or operational change, when comparing to following KPIs?**
Question 14	**How important is it to provide information and/or educate customers when implementing a new policy or operational change, when comparing to following KPIs?**
Question 15	**How important is the interaction between a building and it's occupants, when comparing to following KPIs?**

Appendix C – Instrument Development – Materiality Assessment

Appendix Table 2. Materiality Assessment Survey Responses

Metrics & Submetrics	Sales Revenue	Net Profit	Staff Retention	Operational Efficiency	Public Opinion	Website Traffic	Customer Satisfaction	Customer Retention
Energy								
Type of electricity								
	Slightly Important	Moderately Important	Moderately Important	Unimportant	Very Important	Unimportant	Slightly Important	Important
	Slightly Important	Moderately Important	Moderately Important	Slightly Important	Very Important	Slightly Important	Slightly Important	Very Important
	Slightly Important	Moderately Important	Moderately Important	Moderately Important	Important	Moderately Important	Moderately Important	Important
	Slightly Important	Moderately Important	Important	Unimportant	Important	Unimportant	Slightly Important	Moderately Important
	Slightly Important	Moderately Important	Moderately Important	Unimportant	Very Important	Unimportant	Slightly Important	Very Important
	Slightly Important	Slightly Important	Moderately Important	Unimportant	Very Important	Unimportant	Unimportant	Important
	Slightly Important	Moderately Important	Moderately Important	Slightly Important	Important	Slightly Important	Slightly Important	Important
	Slightly Important	Moderately Important	Moderately Important	Slightly Important	Very Important	Slightly Important	Slightly Important	Very Important
Energy monitoring & reporting								
	Slightly Important	Unimportant	Slightly Important	Important	Important	Slightly Important	Slightly Important	Moderately Important

	Slightly Important	**Slightly Important**	**Slightly Important**	**Important**	**Important**	**Unimportant**	**Slightly Important**	**Moderately Important**
	Moderately Important	**Moderately Important**	**Moderately Important**	**Moderately Important**	**Important**	**Slightly Important**	**Moderately Important**	**Moderately Important**
	Slightly Important	**Slightly Important**	**Slightly Important**	**Important**	**Important**	**Slightly Important**	**Slightly Important**	**Slightly Important**
	Slightly Important	**Slightly Important**	**Slightly Important**	**Important**	**Important**	**Unimportant**	**Slightly Important**	**Slightly Important**
	Slightly Important	**Slightly Important**	**Slightly Important**	**Important**	**Important**	**Slightly Important**	**Slightly Important**	**Moderately Important**
	Slightly Important	**Unimportant**	**Slightly Important**	**Important**	**Important**	**Slightly Important**	**Slightly Important**	**Slightly Important**
	Moderately Important	**Moderately Important**	**Moderately Important**	**Important**	**Important**	**Moderately Important**	**Unimportant**	**Unimportant**
Cost of energy								
	Slightly Important	**Very Important**	**Unimportant**	**Moderately Important**	**Unimportant**	**Unimportant**	**Slightly Important**	**Moderately Important**
	Moderately Important	**Very Important**	**Slightly Important**	**Unimportant**	**Unimportant**	**Unimportant**	**Important**	**Very Important**
	Moderately Important	**Important**	**Slightly Important**	**Slightly Important**	**Slightly Important**	**Unimportant**	**Important**	**Important**
	Slightly Important	**Important**	**Slightly Important**	**Important**	**Slightly Important**	**Unimportant**	**Slightly Important**	**Slightly Important**
	Moderately Important	**Very Important**	**Slightly Important**	**Unimportant**	**Unimportant**	**Unimportant**	**Important**	**Very Important**
	Slightly Important	**Very Important**	**Unimportant**	**Moderately Important**	**Unimportant**	**Slightly Important**	**Slightly Important**	**Moderately Important**
	Slightly Important	**Very Important**	**Unimportant**	**Moderately Important**	**Unimportant**	**Unimportant**	**Slightly Important**	**Slightly Important**

Appendix C – Instrument Development – Materiality Assessment

	Moderately Important	Very Important	Slightly Important	Unimportant	Unimportant	Unimportant	Slightly Important	Slightly Important
Infrastructure & Buildings								
Efficiency of equipment & machinery								
	Very Important	Important	Important	Very Important	Moderately Important	Unimportant	Slightly Important	Slightly Important
	Very Important	Important	Moderately Important	Very Important	Slightly Important	Unimportant	Moderately Important	Important
	Important	Important	Moderately Important	Important	Slightly Important	Slightly Important	Moderately Important	Important
	Very Important	Important	Very Important	Very Important	Moderately Important	Slightly Important	Slightly Important	Slightly Important
	Very Important	Important	Important	Very Important	Slightly Important	Unimportant	Moderately Important	Important
	Very Important	Important	Important	Very Important	Moderately Important	Unimportant	Slightly Important	Moderately Important
	Very Important	Important	Important	Important	Moderately Important	Unimportant	Slightly Important	Slightly Important
	Very Important	Important	Moderately Important	Very Important	Moderately Important	Slightly Important	Moderately Important	Important
Thermal performance of buildings occupied								
	Moderately Important	Important	Very Important	Important	Important	Unimportant	Important	Important

	Moderately Important	**Important**	**Very Important**	**Slightly Important**	**Important**	**Slightly Important**	**Very Important**	**Important**
	Moderately Important	**Important**	**Important**	**Slightly Important**	**Important**	**Moderately Important**	**Important**	**Important**
	Moderately Important	**Important**	**Important**	**Very Important**	**Important**	**Slightly Important**	**Important**	**Important**
	Moderately Important	**Important**	**Very Important**	**Slightly Important**	**Important**	**Moderately Important**	**Important**	**Important**
	Moderately Important	**Important**	**Important**	**Important**	**Important**	**Unimportant**	**Important**	**Very Important**
	Moderately Important	**Important**	**Very Important**	**Important**	**Important**	**Unimportant**	**Important**	**Moderately Important**
	Moderately Important	**Important**	**Very Important**	**Slightly Important**	**Moderately Important**	**Slightly Important**	**Very Important**	**Important**
Frequency of maintenance to buildings & infrastructure								
	Very Important	**Important**	**Important**	**Very Important**	**Important**	**Slightly Important**	**Important**	**Moderately Important**
	Very Important	**Important**	**Very Important**	**Very Important**	**Moderately Important**	**Slightly Important**	**Very Important**	**Moderately Important**
	Important	**Important**	**Important**	**Important**	**Moderately Important**	**Slightly Important**	**Important**	**Moderately Important**
	Very Important	**Important**	**Important**	**Very Important**	**Important**	**Slightly Important**	**Important**	**Moderately Important**
	Very Important	**Important**	**Very Important**	**Important**	**Moderately Important**	**Slightly Important**	**Very Important**	**Moderately Important**

	Very Important	Important	Important	Very Important	Important	Slightly Important	Important	Important
	Very Important	Important	Important	Very Important	Important	Slightly Important	Moderately Important	Moderately Important
	Very Important	Very Important	Very Important	Very Important	Moderately Important	Slightly Important	Very Important	Moderately Important
Goods & Services								
Environmental impact of the goods or services by a business								
	Important	Important	Important	Slightly Important	Very Important	Important	Important	Very Important
	Very Important	Important	Important	Moderately Important	Important	Slightly Important	Very Important	Very Important
	Important	Important	Important	Moderately Important	Important	Slightly Important	Important	Important
	Important	Important	Very Important	Slightly Important	Very Important	Important	Very Important	Very Important
	Very Important	Important	Very Important	Moderately Important	Important	Moderately Important	Very Important	Very Important
	Important	Important	Very Important	Moderately Important	Very Important	Important	Very Important	Very Important
	Important	Important	Important	Moderately Important	Very Important	Very Important	Important	Very Important
	Very Important	Important	Important	Moderately Important	Important	Slightly Important	Very Important	Very Important
Sustainability credentials of supply chain partners								

	Slightly Important	**Slightly Important**	**Slightly Important**	**Unimportant**	**Important**	**Slightly Important**	**Moderately Important**	**Moderately Important**
	Unimportant	**Slightly Important**	**Unimportant**	**Unimportant**		**Moderately Important**	**Unimportant**	**Unimportant**
	Slightly Important	**Slightly Important**	**Slightly Important**	**Slightly Important**	**Moderately Important**	**Slightly Important**	**Unimportant**	**Unimportant**
	Slightly Important	**Moderately Important**	**Slightly Important**	**Unimportant**	**Important**	**Slightly Important**	**Moderately Important**	**Moderately Important**
	Unimportant	**Slightly Important**	**Slightly Important**	**Unimportant**	**Slightly Important**	**Moderately Important**	**Unimportant**	**Unimportant**
	Slightly Important	**Slightly Important**	**Unimportant**	**Unimportant**	**Important**	**Slightly Important**	**Slightly Important**	**Moderately Important**
	Slightly Important	**Slightly Important**	**Slightly Important**	**Slightly Important**	**Important**	**Slightly Important**	**Moderately Important**	**Moderately Important**
	Unimportant	**Unimportant**	**Unimportant**	**Unimportant**	**Slightly Important**	**Slightly Important**	**Unimportant**	**Unimportant**
Quantity and frequency of goods procured								
	Very Important	**Very Important**	**Slightly Important**	**Important**	**Moderately Important**	**Unimportant**	**Unimportant**	**Unimportant**
	Important	**Important**	**Moderately Important**	**Very Important**	**Moderately Important**	**Unimportant**	**Unimportant**	**Unimportant**
	Important	**Important**	**Moderately Important**	**Important**	**Moderately Important**	**Unimportant**	**Unimportant**	**Unimportant**
	Very Important	**Very Important**	**Slightly Important**	**Important**	**Important**	**Unimportant**	**Unimportant**	**Unimportant**
	Important	**Important**	**Moderately Important**	**Important**	**Moderately Important**	**Slightly Important**	**Unimportant**	**Unimportant**

	Very Important	Very Important	Slightly Important	Important	Moderately Important	Unimportant	Unimportant	Unimportant
	Important	Important	Slightly Important	Important	Moderately Important	Unimportant	Unimportant	Unimportant
	Important	Important	Moderately Important	Very Important	Moderately Important	Unimportant	Unimportant	Unimportant
Carbon Emissions								
Operational carbon emissions								
	Important	Important	Important	Moderately Important	Very Important	Very Important	Moderately Important	Important
	Important	Important	Important	Important	Very Important	Slightly Important	Slightly Important	Important
	Moderately Important	Moderately Important	Important	Important	Very Important	Slightly Important	Slightly Important	Moderately Important
	Important	Important	Moderately Important	Moderately Important	Very Important	Very Important	Moderately Important	Moderately Important
	Important	Very Important	Important	Important	Very Important	Slightly Important	Slightly Important	Moderately Important
	Moderately Important	Important	Very Important	Moderately Important	Very Important	Very Important	Moderately Important	Important
	Important	Important	Important	Moderately Important	Very Important	Very Important	Slightly Important	Important
	Important	Important	Important	Very Important	Very Important	Slightly Important	Slightly Important	Important
Value chain emissions								

Appendix C – Instrument Development – Materiality Assessment

	Slightly Important	Slightly Important	Moderately Important	Slightly Important	Important	Moderately Important	Slightly Important	Moderately Important
	Unimportant	Unimportant	Important	Unimportant	Important	Unimportant	Unimportant	Slightly Important
	Unimportant	Unimportant	Moderately Important	Slightly Important	Important	Slightly Important	Slightly Important	Slightly Important
	Slightly Important	Slightly Important	Moderately Important	Moderately Important	Important	Slightly Important	Moderately Important	Moderately Important
	Unimportant	Unimportant	Important	Slightly Important	Important	Slightly Important	Slightly Important	Slightly Important
	Slightly Important	Slightly Important	Moderately Important	Slightly Important	Important	Important	Slightly Important	Moderately Important
	Slightly Important	Slightly Important	Moderately Important	Slightly Important	Important	Moderately Important	Moderately Important	Moderately Important
	Unimportant	Unimportant	Important	Unimportant	Important	Slightly Important	Unimportant	Unimportant
Concept of 'Net-Zero Carbon'								
	Important	Important	Moderately Important	Slightly Important	Very Important	Very Important	Important	Important
	Important	Important	Important	Unimportant	Important	Moderately Important	Slightly Important	Important
	Important	Important	Moderately Important	Slightly Important	Important	Important	Moderately Important	Moderately Important
	Important	Very Important	Moderately Important	Slightly Important	Important	Very Important	Important	Moderately Important
	Important	Important	Very Important	Unimportant	Important	Moderately Important	Slightly Important	Important
	Important	Important	Important	Slightly Important	Very Important	Very Important	Important	Important

Appendix C – Instrument Development – Materiality Assessment

	Very Important	Very Important	Very Important	Unimportant	Very Important	Important	Moderately Important	Moderately Important
	Important	Important	Important	Unimportant	Important	Moderately Important	Slightly Important	Important
People & Behaviour								
Train & educate employees								
	Important	Important	Very Important	Very Important	Slightly Important	Unimportant	Important	Slightly Important
	Moderately Important	Moderately Important	Important	Important	Slightly Important	Slightly Important	Important	Slightly Important
	Moderately Important	Important	Moderately Important	Important	Slightly Important	Slightly Important	Important	Moderately Important
	Important	Important	Very Important	Important	Slightly Important	Unimportant	Important	Moderately Important
	Moderately Important	Moderately Important	Important	Important	Moderately Important	Slightly Important	Moderately Important	Slightly Important
	Important	Important	Very Important	Very Important	Slightly Important	Unimportant	Important	Moderately Important
	Important	Important	Very Important	Important	Slightly Important	Unimportant	Important	Slightly Important
	Moderately Important	Moderately Important	Important	Important	Slightly Important	Slightly Important	Important	Slightly Important
Provide information and educate customers								
	Important	Very Important	Important	Slightly Important	Very Important	Important	Very Important	Very Important

	Important	Important	Important	Slightly Important	Important	Moderately Important	Very Important	Very Important
	Important	Moderately Important	Important	Slightly Important	Important	Moderately Important	Important	Important
	Important	Very Important	Important	Slightly Important	Important	Important	Very Important	Very Important
	Important	Important	Very Important	Slightly Important	Important	Moderately Important	Very Important	Important
	Important	Very Important	Important	Slightly Important	Very Important	Important	Very Important	Very Important
	Important	Very Important	Important	Slightly Important	Very Important	Important	Very Important	Very Important
	Important	Moderately Important	Important	Slightly Important	Important	Moderately Important	Very Important	Very Important
Interaction between a building and its occupants								
	Very Important	Important	Very Important	Very Important	Moderately Important	Slightly Important	Important	Important
	Moderately Important	Moderately Important	Very Important	Moderately Important	Slightly Important	Slightly Important	Very Important	Very Important
	Important	Moderately Important	Very Important	Important	Moderately Important	Moderately Important	Important	Important
	Very Important	Important	Important	Very Important	Moderately Important	Slightly Important	Important	Important
	Moderately Important	Moderately Important	Very Important	Important	Slightly Important	Slightly Important	Very Important	Very Important
	Very Important	Important	Very Important	Very Important	Moderately Important	Moderately Important	Important	Very Important

	Very Important	**Important**	**Very Important**	**Very Important**	**Moderately Important**	**Slightly Important**	**Important**	**Important**
	Moderately Important	**Moderately Important**	**Very Important**	**Moderately Important**	**Slightly Important**	**Slightly Important**	**Very Important**	**Very Important**

Appendix C – Instrument Development – Materiality Assessment

Appendix Table 3. Materiality Assessment Scoring

Key Metric	Sub Metric	Sales Revenue	Net Profit	Staff Retention	Operational Efficiency	Public Opinion	Website Traffic	Customer Satisfaction	Customer Retention
Energy	**Type of electricity**	**16**	**23**	**25**	**13**	**37**	**13**	**16**	**34**
	Energy monitoring & reporting	**18**	**16**	**18**	**31**	**32**	**15**	**16**	**19**
	Cost of energy	**20**	**38**	**13**	**18**	**10**	**9**	**22**	**26**
Infrastructure & Buildings	**Efficiency of equipment & machinery**	**39**	**32**	**30**	**38**	**21**	**11**	**20**	**25**
	Thermal performance of buildings occupied	**24**	**32**	**37**	**25**	**31**	**15**	**34**	**32**
	Frequency of maintenance to buildings & infrastructure	**39**	**33**	**35**	**38**	**28**	**16**	**34**	**25**
Goods & Services	**Environmental impact of the goods & services sold**	**35**	**32**	**35**	**22**	**36**	**26**	**37**	**39**
	Sustainability credentials of supply chain partners	**13**	**16**	**13**	**10**	**27**	**18**	**15**	**16**
	Quantity and frequency of goods procured	**35**	**35**	**20**	**34**	**25**	**9**	**8**	**8**
Carbon Emissions	**Operational carbon emissions**	**30**	**32**	**32**	**29**	**40**	**28**	**19**	**29**
	Value chain emissions	**12**	**12**	**27**	**15**	**32**	**19**	**16**	**19**
	Concept of 'Net-Zero Carbon'	**33**	**34**	**31**	**12**	**35**	**32**	**24**	**29**

People & Behaviour	**Train & educate employees**	**28**	**29**	**35**	**34**	**17**	**12**	**31**	**19**
	Provide information and educate customers	**32**	**34**	**33**	**16**	**35**	**28**	**39**	**38**
	Interaction between a building and its occupants	**33**	**28**	**39**	**34**	**21**	**18**	**35**	**36**

Appendix Table 4. Materiality Assessment Data Synthesis

Metrics	Metric Type	Count
Energy	**Metric**	**498**
Type of electricity	**Submetric**	**177**
Energy monitoring & reporting	**Submetric**	**165**
Cost of energy	**Submetric**	**156**
Infrastructure & Buildings	**Metric**	**694**
Efficiency of equipment & machinery	**Submetric**	**216**
Thermal performance of buildings occupied	**Submetric**	**230**
Frequency of maintenance to buildings & infrastructure	**Submetric**	**248**
Goods & Services	**Metric**	**564**
Environmental impact of the goods or services by a business	**Submetric**	**262**
Sustainability credentials of supply chain partners	**Submetric**	**128**
Quantity and frequency of goods procured	**Submetric**	**174**
Carbon Emissions	**Metric**	**621**
Operational carbon emissions	**Submetric**	**239**
Value chain emissions	**Submetric**	**152**
Concept of 'Net-Zero Carbon'	**Submetric**	**230**
People & Behaviour	**Metric**	**704**
Train & educate employees	**Submetric**	**205**
Provide information and educate customers	**Submetric**	**255**
Interaction between a building and its occupants	**Submetric**	**244**

Appendix D – Carbon Management Instrument

Appendix D1 – Carbon Management Questionnaire

-Used for auditing a company's assets and infrastructure in relation to fabric and energy efficiency-

The following questionnaire survey is for use during Phase 1: Base Case, of the carbon management framework (CMF-V3) developed as part of the postgraduate research project completed by Tom Johnston at the University of Liverpool. It has been developed to be used in preparation for and during energy and carbon audits of a company's facilities, vehicles, and general infrastructure. The survey consists of four main sections:

SECTION 1 - COMPANY & FINANCIAL INFORMATION

- Gathers basic company information on finances, sectors of operation, location, and building types occupied.

SECTION 2 – PROJECT SCOPE

- Identifies the drivers and business goals of the user to help narrow the focus. It encourages the user to set goals & targets and determines what type of data is to be collected for the assessment.

SECTION 3 – BUILDINGS & INFRASTRUCTURE AUDIT

- Aims to establish information around the users' buildings and infrastructure, there are 9 sub-sections included:
    - General building information
    - Building fabric
    - Lighting
    - Heating, cooling, and ventilation
    - Office equipment
    - Catering equipment
    - Industrial/Commercial Refrigeration
    - Specialist equipment & machinery
    - Vehicles

SECTION 4 – ENERGY DATA PRE-ASSESSMENT

- This section helps the user to identify the type of data required and helps to identify what format the data will be in.

All responses will be treated as confidential. The information and data gathered may be used in academic publications if the participant is willing and the 'Questionnaire Consent Form' has been signed by the relevant parties. It is important to mention that all names relating to the company will remain anonymous unless otherwise discussed.

If you are willing for the data gathered to be disseminated for research purposes, please read the participant information sheet and sign & date the consent form. – Forms should be sent out with questionnaire.

For further information or queries please contact Tom Johnston (t.johnston@liverpool.ac.uk)

COMPANY & FINANCIAL INFORMATION

Company Name:	
No. of employees:	
No. of buildings occupied:	
No. of sites operated:	

a. **What period did the company use for the previous years financial reporting?**

Example: April 2018 - March 2019

b. **Sales Revenue**

Previous financial year

£

c. **Balance Sheet Total**

Previous financial year

£

d. **Company Sector**

What sector and/or sub-sector(s) does the company operate in?

e. **Please try and explain what it is that your company does?**

This can include any value-added services (VAS) that you may also provide to customers in addition to your core business

£

f. Does the company own the building/s or the land where the organisation is based?

☐ **Yes**
☐ **No,** if no please expand below on land ownership

Is the land/building rented, on a long leasehold, or other?
Does the company have permission to build or upgrade building fabric?

g. Where is the site located?

☐ Urban area

☐ Rural area

☐ Suburban area

☐ Industrial Park

☐ Science/Research/Technology Park

☐ Business Park

☐ Retail Park

h. Briefly explain the building/s structure and/or land where the business is located

Example 1. Building constructed of brick with a solid roof to support external weight (such as solar panels) – no external space available

Example 2. 5 acres of open greenfield land containing a single building occupying approx. 20% of available land, 20% used as a car park for staff and visitors.

Building 1 (INSERT BUILDING NAME):

Building 2 (INSERT BUILDING NAME):

Building 3 (INSERT BUILDING NAME):

Building 4 (INSERT BUILDING NAME):

Building 5 (INSERT BUILDING NAME):

PROJECT SCOPE

i. What do you aim to achieve from undertaking this energy reduction project?

☐ Reduction in operational energy cost

☐ Reduction in carbon emissions

☐ Improved thermal comfort inside buildings

☐ Total ban on all fossil fuels

☐ Percentage of energy supply to come from on-site renewable energy

☐ Percentage of energy supply to come from off-site renewable energy

Please use the box below to expand on your primary aim for this project (if required)

j. What are the company's key drivers?

☐ Environmental (reducing emissions)

☐ Cost-Saving

☐ Legislative/Regulations

☐ CSR

☐ Employee Well-being

☐ Public Relations

Appendix D – Carbon Management Instruments

Please use the box below to expand on your key drivers for this project (if required)

k. Define your targets

It is important for any company to set a number of targets whilst attempting to reduce and mitigate their carbon emissions, this demonstrates a clear goal to work toward, as well as providing a clear set of goals for strategic planning.

- Baseline period should be 12-months – it is recommended to have complete energy data for the period stated. It is preferable if a single calendar year is chosen as the baseline year period (e.g. Jan 19 – Dec 19

- Project Target Date does not have to be specific at this stage, rather a realistic, for when the business

- Science-based targets are a set of goals developed by a business to help provide a clear strategy to reduce and mitigate against carbon emissions. It is not necessary to set a science-based target at this time and can be set later.

E.g. The company will aim to reduce operational carbon emissions by 50% by 2030, with a further ambition to become a net-zero carbon company by 2040.

Baseline Period Start Date	
Baseline Period End Date	
Project Target Date	
Science-Based Targets (if any)	

l. What areas of the organisation would you like to focus on at this stage?

☐ Energy Supply – Switching to a renewable energy source

☐ Energy Efficiency – Updating existing lighting, equipment, and machinery

☐ Thermal Efficiency – Improving building fabric

☐ Operational Management – Educating members of staff on more sustainable practices

If there are any other areas your company would like to focus on, please state in the box below

m. What are the operational boundaries (or emissions scopes) for this stage project?

Operational boundaries are defined as the emissions associated with a company's operations, categorising them as either direct or indirect emissions, and choosing the scope of accounting and reporting. (World Resources Institute and World Business Council for Sustainable Development, 2004)

A brief description of each scope is included below to help with choosing which scopes are relevant for this project.

- **Scope 1** includes emissions produced *directly* from business operations. For instance, emissions produced from combustion in owned or controlled boilers, furnaces, or vehicles.
    - e.g. Gas-powered space heating or LPG-fueled cooking hobs etc...
- **Scope 2** accounts for *indirect* emissions that occur as a result of the generation of purchased electricity.
    - e.g. Electricity used on site that has been purchased from the national grid.
- **Scope 3** accounts for all other emissions produced as a result of 3rd party activities, i.e. the company's supply chain.
    - For example, visitor cars when onsite company property, delivery of products to be used or sold by the company, or

Please tick which emissions scopes are too be included for this assessment.

It is strongly recommended that scopes 1 & 2 are included for an operational carbon assessment.

Emissions Scopes	Energy/Emissions Source
☐ Scope 1	
☐ Scope 2	
☐ Scope 3	

BUILDINGS & INFRASTRUCTURE AUDIT

If you operate multiple buildings, the following section can be completed multiple times for each building or site that the company operates.

Building or Site Information

n. **Please state the name of the building/site being audited**

If the building/site does not have a specific name, please use the address or location.

o. Has a site survey been conducted to assess the business-as-usual operations relating to building fabric or building energy?

☐ Yes ☐ No ☐ Partially

If 'No' or 'Partially' the following questions may be able to help identify what to look for.

p. **Briefly explain the type of operation that occurs within this building**

Example answer - Typical occupancy hours: Mon-Fri (07:30 - 18:00), Typical operation hours: 24/7

q. **Briefly explain the building's typical occupancy and operation hours.**

Example answer - Typical occupancy hours: Mon-Fri (07:30 - 18:00), Typical operation hours: 24/7

r. **Briefly explain the building's typical occupancy and operation hours.**

Example answer - Typical occupancy hours: Mon-Fri (07:30 - 18:00), Typical operation hours: 24/7

s. **Is there an electric meter installed in the building?**

Question refers to this specific building only, if a singular meter point is shared across multiple buildings, please use the 'other' box to provide more detail.

☐ Yes

☐ No

☐ Partially

t. **How many Gas meters are installed in the building?**

Please only answer for this specific building

u. **Is there an electric meter installed in the building?**

Question refers to this specific building only, if a singular meter point is shared across multiple buildings, please use the 'other' box to provide more detail.

☐ Yes

☐ No

☐ Partially

v. **How many gas meters are installed in the building?**

Please only answer for this specific building

Building Fabric

w. Building Foundations (Substructure)

☐ Individual footing or isolated footing

☐ Combined footing

☐ Strip foundation

☐ Raft or mat foundation

☐ Pile foundation

☐ Drilled shafts or caussons

☐ Unsure

☐ Other…………………………….

x. Building Frame (Superstructure)

☐ Brick and block

☐ Timber frame (open panel)

☐ Timber frame (closed-panel)

☐ Insulated concrete formwork (ICF)

☐ Steel framed

☐ Structurally insulated panels (SIPs)

☐ Unsure

☐ Other…………………………….

y. What type of glazing is installed in the building?

If you know the specific type of glass used in the building, please expand further using the 'other' option.

☐ Single glazing

☐ Double glazing

☐ Triple glazing

☐ Secondary glazing

☐ Unsure

☐ Other……………………………..

z. Does the building have any wall insulation?

Please select where the wall insulation is located, use 'other' box to expand on the type of insulation if the information is known.

If the building was built before the 1920s then it is likely to have solid walls, in this case either internal or external wall insulation may have been installed.

☐ Cavity wall insulation

☐ Internal wall insulation

☐ External wall insulation

☐ No wall insulation

☐ Unsure

☐ Other……………………………..

aa. Does the building have any ceiling or loft insulation installed?

Use 'other' option to expand on the type of insulation installed if the information is known.

☐ Yes, within last 10 years

☐ Yes, within last 20 years

☐ No

☐ Unsure

☐ Other…………………………….

bb. Does the building have floor insulation?

Use 'other' option to expand on the type of insulation installed if the information is known.

☐ Suspended floor insulation

☐ Solid floor insulation

☐ Crawl space insulation

☐ No floor insulation

☐ Unsure

☐ Other…………………………….

Lighting

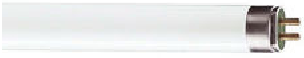
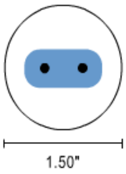
cc. Has a lighting audit been conducted in the last 12 months?

☐ Yes

☐ No

☐ Partially

dd. What is the predominant lighting in the workplace? Please select as many as necessary.

☐ Halogen Bulb	
☐ Compact Fluorescent Lamp (CFL)	
☐ T5 Fluorescent Lamp	 
☐ T8 Fluorescent Lamp	 
☐ T12 Fluorescent Lamp	 
☐ LED Lighting	

☐ Unsure	
☐ Other (please specify)	

ee. Are there any motion (PIR) sensors installed to control the lighting?

☐ Yes in all suitable locations

☐ Yes in most of the suitable locations

☐ Yes in some of the suitable locations

☐ No

☐ Unsure

☐ Other (Please specify)……………………………………………………

Heating & Cooling

ff. Is the building Heated?

☐ Yes

☐ No

☐ Unsure

gg. If yes, what heating systems are installed in the building/s.
If no, skip question

☐ Gas fuelled space heater

☐ Electrically powered space heater

☐ Gas boiler with central heating system

☐ Radiant heaters

☐ Infrared panel heaters

☐ Electric convection heaters

☐ Fan heater

☐ Underfloor heating (electric)

☐ Unfloor heating (wet)

☐ Oil fueled heater

☐ Heat pump

☐ Other (please specify) …………………………………………………

☐ Unsure

hh. Is there a HVAC system installed in the building?

HVAC stands for Heating, Ventilation, and Air Conditioning and is typically used in commercial buildings to provide a stable and comfortable temperature and can be used to improve indoor air quality.

☐ Yes

☐ No

☐ Unsure

ii. If yes, what type of HVAC system is installed?

☐ Heating & cooling split system

☐ Hybrid split system

☐ Duct-free (mini-split)

☐ Packaged heating and air

☐ Unsure

☐ Other……………………………..

jj. Does the building have a specific cooling system installed?

This may be either Passive cooling (e.g. natural ventilation or solar shading) or Active cooling (e.g. mechanical ventilation, driven by fans).

☐ Yes

☐ No

☐ Unsure

kk. If yes, what type of cooling system is installed?

☐ Natural ventilation (wind-driven cross ventilation)

☐ Solar shading

☐ Earth-to-air heat exchanges

☐ Mechanical (or forced) ventilation

☐ VRF system

☐ Evaporative cooling (e.g. misting fans)

☐ Unsure

☐ Other…………………………….

Office Equipment

ll. Does the building contain office equipment?

Office equipment refers to computers, laptops, printers etc...

Specialist equipment (e.g. 3D printers) will be accounted for in a later question.

☐ Yes

☐ No

☐ Unsure

mm. If yes, select the office equipment installed.

☐ Computers

☐ Laptops

☐ Monitors

☐ Telecomms & VoIP

☐ Network routers

☐ Printers or multipurpose machines

☐ Paper shredder

☐ Other, please state in box below

nn. Typical operating hours (office equipment)

Please explain the typical hours that office equipment is used within the building.

Example answer: Mon-Fri (08:00 - 17:00), with occasional use on weekends.

Appendix D – Carbon Management Instruments

Catering Equipment

oo. Does the building contain catering equipment?

Catering equipment refers to anything from a coffee/tea station to a fully equipped kitchen.

☐ Yes

☐ No

☐ Unsure

pp. If yes, how would you describe the catering area in the building?

If the building has more than one of a single option (e.g. 2x kitchenettes) please use 'other' box to specify more detail.

☐ Coffee/tea station

☐ Kitchenette with basic appliances (kettle, microwave, fridge, sink etc.)

☐ Fully-equiped self-catered kitchen (inc. oven and hob)

☐ Industrial kitchen (staffed)

☐ Other, please state in box below

qq. Typical operating hours (catering equipment)

Please explain the typical hours that catering equipment is used within the building.

Example answer: High-usage Mon-Fri (11:00 - 15:00), with occasional use outside these hours.

Industrial/Commercial Refrigerants

rr. Does the building contain any equipment that requires refrigerants

This may include fridges, freezers, and cold stores that are located either inside or outside of the building and used for business activities or commercial purposes. Alternatively, it could be AC equipment.

N.b.. A fridge in a kitchenette used to store milk and staff food should be EXCLUDED

☐ Yes

☐ No

☐ Unsure

ss. If yes, expand on the type of refrigeration units installed.

Example answer: 2x large cold stores (1 chilled & 1 frozen), 3x drinks fridges, 2x double-height fridges, a chest freezer.

tt. Typical operating hours (refrigeration equipment)

Please explain the typical hours that refrigeration equipment is used within the building.

Example answer: 2x large cold stores + chest freezer = 24/7 ; 3x drinks fridges + 2x double-height fridges = 14 hrs (07:00 - 21:00)

Specialist Equipment & Machinery

uu. Does the building contain any specialist equipment or machinery?

This refers to any equipment or machinery used within the building that contributes to the normal operation of business activities.

This may include: Manufacturing equipment, processing machinery, power tools, garage equipment, lift (elevator), industrial grow lights, waste & fume extraction etc...

Please note that this does not include refrigeration as this has already been covered.

☐ Yes

☐ No

☐ Unsure

vv. If yes, specialist equipment & machinery used and how it is powered.

This may include: Manufacturing equipment, processing machinery, power tools, garage equipment, lift (elevator), industrial grow lights, waste & fume extraction etc...

***Example answer**:*

Electricity - 3D printer, 2x CNC machine, power washer, lift (elevator)
Diesel - Air compressor, generator, mini digger
Petrol - Tiller, lawnmower, disc cutter
LPG - forklift, kiln
Natural Gas – Furnace

ww. Typical operating hours (refrigeration equipment)

Please explain the typical hours that specialist equipment & machinery is used within the building.

Example answer 1: Air compressor (2hrs/day, 6days/wk), Injection moulding machine (8hrs/day, 4 days/week)

Example answer 2: Industrial grow lights (112hrs/wk), water filtration machine (24/7), fume extraction (6hrs/day, 7days/wk))

Vehicles

xx. Does the company own or operate (lease) any vehicles?

☐ Yes

☐ No

☐ Unsure

yy. If yes, what types of vehicles are operated?

If the building has more than one of a single option (e.g. 2x kitchenettes) please use 'other' box to specify more detail.

☐ Company cars

☐ Delivery vehicles

☐ Service vehicles

☐ Unsure

☐ Other, please state in box below

zz. What fuels are used in vehicles?

☐ Petrol

☐ Diesel

☐ Biofuel

☐ Hydrogen

☐ Compressed natural gas (CNG)

☐ Liquified petroleum gas (LPG)

☐ Electric

☐ Unsure

☐ Other, please state in box below

ENERGY DATA PREASSESSMENT

For a comprehensive carbon assessment, it is recommended that the company provides a minimum of 12-months of historic energy data, however, it is preferable to provide historic data for as long as possible, this will improve the accuracy of energy forecasting.

aaa. Is there at least 12 months of energy consumption data available?

Usually in the form of energy bills or historic spreadsheets.

☐ Yes

☐ No

☐ Partially

bbb. Please select which of the following energy sources are used by the company.

☐ Grid-purchased electricity

☐ Grid-supplied natural gas

☐ Gaseous fuels stored on site

☐ Liquid fuels stored on site

☐ Solid fuels stored on site

☐ Refrigerants used in commercial refrigeration and air conditioning

☐ Vehicle fuels

☐ Bioenergy (including biofuels, biomass, and biogas)

Grid-Purchased Electricity

ccc. If applicable, select the type(s) of electricity contract(s)

Multiple options can be chosen if there are a number of contracts in place for different buildings or sites. If multiple boxes are chosen, please use the box to breakdown the contracts in place.

☐ **Brown electricity** – (combination of fossil fuels, low-carbon fuels, and renewables)

☐ **Green electricity** (combination of low-carbon fuels & renewables)

☐ **100% renewably sourced electricity**

☐ **Power purchase agreement**

☐ **Self generation of renewable energy**

☐ Unsure

ddd. If applicable, state the length remaining on your electricity contract(s)

eee. Please state the number of electricity meters in the building(s) or site(s).

fff. Are any sub-meters installed? If yes, please expand on how the building(s) or site(s) have been sub-metered.

Appendix D – Carbon Management Instruments

Grid-Purchased Natural Gas

ggg. If applicable, select the type(s) of natural gas contract(s)

Multiple options can be chosen if there are a number of contracts in place for different buildings or sites. If multiple boxes are chosen, please use the box to breakdown the contracts in place.

☐ **Standard contract**

☐ **Green gas + Offsets** (combination of biogas/biomethane and carbon offsets)

☐ **100% green gas** (100% biogas/biomethane

☐ **Self generation of green gas** (through the process of anaerobic digestion)

☐ Unsure

hhh. If applicable, state the length remaining on your gas contract(s)

iii. Please state the number of gas meters in the building(s) or site(s).

jjj. Are any sub-meters installed? If yes, please expand on how the building(s) or site(s) have been sub-metered.

Gaseous Fuels

kkk. If applicable, select the gaseous fuels used

Multiple options can be chosen

☐ Butane

☐ CNG

☐ LNG

☐ LPG

☐ Natural gas

☐ Natural gas (100% mineral blend)

☐ Other petroleum gas

☐ Propane

☐ Unsure

☐ Other, please state in box below

lll. If applicable, select the unit(s) in which your gaseous fuel is recorded

☐ tonnes

☐ litres

☐ kWh

☐ Cubic meters

mmm. Please state how the gas is stored on site(s).

nnn. Are any sub-meters installed? If yes, please expand on how the building(s) or site(s) have been sub-metered to measure consumption.

Appendix D – Carbon Management Instruments

Liquid Fuels

ooo. **If applicable, select the liquid fuels used**

Multiple options can be chosen

☐ Petrol

☐ Diesel

☐ Fuel oil

☐ Gas oil (red diesel)

☐ Lubricants

☐ Burning oil

☐ Kerosene

☐ Waste oils

☐ Unsure

☐ Other, please state in box below

ppp. **If applicable, select the unit(s) in which your liquid fuel is recorded**

☐ tonnes

☐ litres

☐ kWh

☐ kg

qqq. **Please state how the liquid fuels are stored on site(s).**

rrr. **Are any sub-meters installed? If yes, please expand on how the building(s) or site(s) have been sub-metered to measure consumption.**

Appendix D – Carbon Management Instruments

Solid Fuels

sss. If applicable, select the solid fuels used

Multiple options can be selected

☐ Coal (industrial, electricity generation, or domestic)

☐ Coking coal

☐ Petroleum coke

☐ Gas oil (red diesel)

☐ Lubricants

☐ Burning oil

☐ Kerosene

☐ Waste oils

☐ Unsure

☐ Other, please state in box below

ttt. If applicable, select the unit(s) in which your solid fuel is recorded

☐ tonnes

☐ kWh

☐ kg

uuu. Please state how the solid fuels are stored on site(s).

vvv. Are any sub-meters installed? If yes, please expand on how the building(s) or site(s) have been sub-metered to measure consumption.

Appendix D – Carbon Management Instruments

Bioenergy

www. If applicable, select the biofuels fuels used

Multiple options can be chosen

☐ Bioethanol

☐ Biodiesel (ME, cooking oil, tallow)

☐ HVO

☐ Bio propane

☐ Biomethane

☐ Bio petrol

☐ Biomass (wood logs, wood chips, wood pellets, grass/straw)

☐ Biogas (biogas or landfill gas)

☐ Unsure

☐ Other, please state in box below

xxx. Select the unit(s) in which your bioenergy is recorded

☐ tonnes

☐ litres

☐ kWh

☐ kg

☐ GJ

yyy. Please state how the bioenergy is stored on site(s).

zzz. Are any sub-meters installed? If yes, please expand on how the building(s) or site(s) have been sub-metered to measure consumption.

Refrigerants

aaaa. If applicable, state the refrigerants used

bbbb. Is equipment that requires refrigerants maintained annually?

☐ Yes

☐ No

☐ Unsure

cccc. Do you know the leakage rates for equipment that requires refrigerants?

☐ Yes

☐ No

☐ Unsure

Passenger Vehicles

dddd. Does the company own or operate (includes leasing) any company cars?

☐ Yes

☐ No

☐ Unsure

eeee. If yes, please select the type of vehicles owned or operated

☐ Small car

☐ Medium car

☐ Large car

☐ Average car

☐ Unsure

ffff. If yes, please detail the number and type of passenger vehicles current in use

e.g., 3x 1.6l petrol vehicles, 15x 2.0l diesel vehicles

gggg. How is vehicle mileage recorded?

Multiple options can be selected

☐ Fuel cards

☐ Expense receipts

☐ HR system

☐ Other, please state in box below

Appendix D – Carbon Management Instruments

Delivery Vehicles

hhhh. Does the company own or operate (includes leasing) any delivery vehicles?

☐ Yes

☐ No

☐ Unsure

iiii. If yes, please select the type of vehicles owned or operated

☐ Van - Class I (up to 1.305 tonnes)

☐ Van - Class II (1.305 to 1.74 tonnes)

☐ Van - Class III (1.74 to 3.5 tonnes)

☐ HGV – Rigid

☐ HGV - Articulated

☐ HGV Refrigerated – Rigid

☐ HGV Refrigerated - Articulated

☐ Other, please state in box below

jjjj. If yes, please detail the number and type of passenger vehicles current in use

e.g., 3x 1.6l petrol vehicles, 15x 2.0l diesel vehicles

kkkk. How is vehicle mileage recorded?

Multiple options can be selected

☐ Fuel cards

☐ Expense receipts

☐ HR system

☐ Other, please state in box below

Energy Demand

IIII. **Briefly explain your energy demand profile if possible, including both day-to-day consumption and seasonal demand.**

E.g. Mains Gas

Daily Demand: High early mornings due to comfort heating

Seasonal Variance: High

Seasonal Demand: High in winter due to heating requirements, Low in summer as only used for minor cooking needs.

Energy Supply	**Daily Demand**	**Seasonal Variance**	**Seasonal Demand**
	(Mornings, Evenings)	***(****Low, Medium, High)*	*(Spring, Summer, Autumn, Winter)*

Thank you for completing the carbon management questionnaire survey!

If you have any feedback, please feel free to let us know how we can improve

Ease of Completion

Multiple options can be selected

☐ ★

☐ ★★

☐ ★★★

☐ ★★★★

☐ ★★★★★

How do you think the survey could be improved

General Feedback

Appendix D2 – Carbon Management Statistical Analysis Model

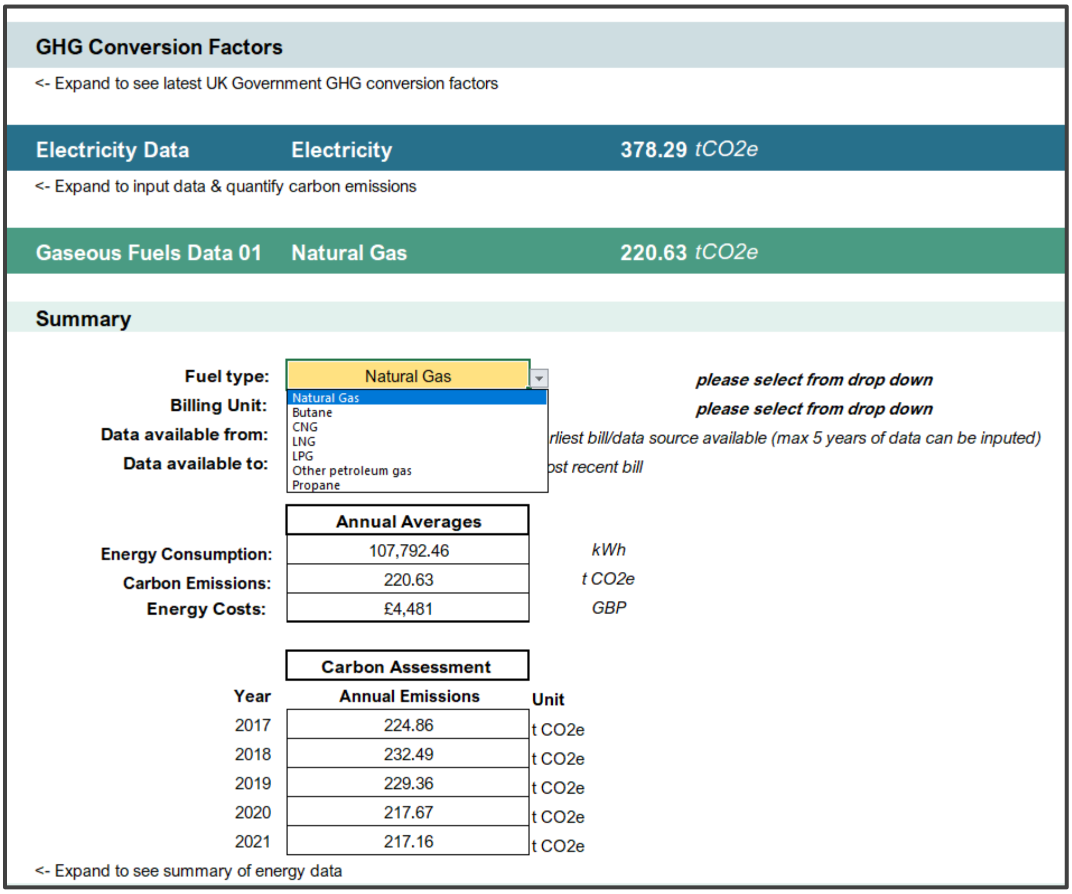
In this appendix, the CM-SAM and its proposed operation is discussed to allow the reader to gain an insight into the instrument and the tools embedded within it. The model has four key tools with each providing a different output, the tools are intended to be straightforward to use, with colour coding to identify the specific cells where the user must input data. An information page provides the user with a brief introduction to the available tools and their use-case, a guide on how to use and operate the statistical analysis model, and a quick link to each of the tools. In addition to the information page, a project scoping page provides a form for users to input the metrics defined during the CMQ. The metrics include setting a baseline assessment period based on either calendar or fiscal year, and selecting which fuels and energy sources are used within a company's operations.

TOOL 1: ENERGY & CARBON ANALYSIS

The first use-case for the CM-SAM in the proposed framework comes following the company and site audit, where the user is guided to start collecting and analysing fuel and energy data in order to quantify operational carbon emissions. This is probably the most useful tool in the collection and provides the user with a template to collection and analysis energy data. The tool is designed to be intuitive to use, starting with a brief introduction explaining the type of data that will be required. There are five predefined energy groups where certain cells are left blank for the user to input data, the energy groups consist of the following:

- Electricity Data
- Gaseous Fuels Data 01, 02, 03
- Liquid Fuels Data 01, 02, 03
- Solid Fuels Data
- Bioenergy Data

The five energy groups were chosen based on predicted energy and fuel consumption patterns for an SME in the UK. Providing multiple options for both gaseous and liquid fuels, permit the user to input data from several different fuel types contained within the same energy grouping. Within each of the energy group categories available, fuel-type and billing unit can be selected from a drop-down list (see Appendix Figure 1), the list of fuels and units followed the UK GHG conversion factors database (BEIS, 2021), this ensured all common fuel types were included in the model.



GHG Conversion Factors

<- Expand to see latest UK Government GHG conversion factors

Electricity Data **Electricity** **378.29** *tCO2e*

<- Expand to input data & quantify carbon emissions

Gaseous Fuels Data 01 **Natural Gas** **220.63** *tCO2e*

Summary

Fuel type: Natural Gas *please select from drop down*

Billing Unit: *please select from drop down*

Data available from: *rliest bill/data source available (max 5 years of data can be inputed)*

Data available to: *ost recent bill*

	Annual Averages	
Energy Consumption:	107,792.46	*kWh*
Carbon Emissions:	220.63	*t CO2e*
Energy Costs:	£4,481	*GBP*

	Carbon Assessment	
Year	**Annual Emissions**	**Unit**
2017	224.86	t CO2e
2018	232.49	t CO2e
2019	229.36	t CO2e
2020	217.67	t CO2e
2021	217.16	t CO2e

<- Expand to see summary of energy data

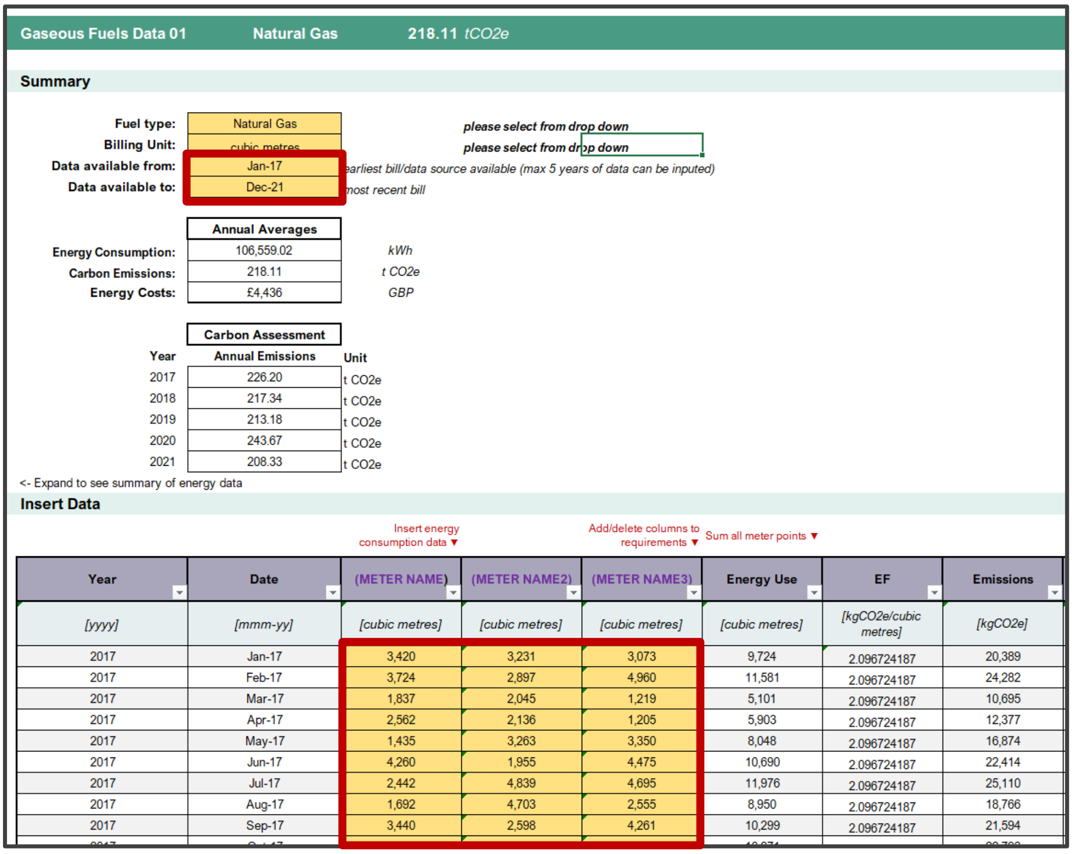
Appendix Figure 1. Screenshot of CM-SAM Model (Energy & Carbon Assessment Tool)

Once the specific fuel type and billing unit was chosen, the automated model selected the relevant conversion factor from the database embedded to enable carbon emissions to be auto-generated without any input. The user can select the period in which they have data available and proceed to input recent and historic[1] energy data for that energy grouping (as shown in Appendix Figure 2). Each energy grouping has three predefined sections allowing for energy readings from three meters or billing accounts, however, the model can be expanded to account for more than three if required. As shown in Appendix Figure 2, here the model has summed the total energy used across three separate meters and auto-generated

---

[1] *Historic data is limited to five years due to model parameters, however, this could easily be expanded once testing is completed. Five years was chosen as it provided enough data to forecast emissions and it was deemed unlikely that a company will have easy access to energy data for later than the five previous years.*

an emissions value based off the conversion factor relevant to that assessment year and fuel-type. Furthermore, the tool computes annual averages for energy consumption, carbon emissions, and energy costs, in addition to a summary of annual carbon emissions.



Gaseous Fuels Data 01 **Natural Gas** **218.11** *tCO2e*

Summary

Fuel type: Natural Gas *please select from drop down*
Billing Unit: cubic metres *please select from drop down*
Data available from: Jan-17 *earliest bill/data source available (max 5 years of data can be inputed)*
Data available to: Dec-21 *most recent bill*

	Annual Averages	
Energy Consumption:	106,559.02	*kWh*
Carbon Emissions:	218.11	*t CO2e*
Energy Costs:	£4,436	*GBP*

	Carbon Assessment	
Year	**Annual Emissions**	**Unit**
2017	226.20	t CO2e
2018	217.34	t CO2e
2019	213.18	t CO2e
2020	243.67	t CO2e
2021	208.33	t CO2e

<- Expand to see summary of energy data

Insert Data

Insert energy consumption data ▼ Add/delete columns to requirements ▼ Sum all meter points ▼

Year	Date	(METER NAME)	(METER NAME2)	(METER NAME3)	Energy Use	EF	Emissions
[yyyy]	*[mmm-yy]*	*[cubic metres]*	*[cubic metres]*	*[cubic metres]*	*[cubic metres]*	*[kgCO2e/cubic metres]*	*[kgCO2e]*
2017	Jan-17	3,420	3,231	3,073	9,724	2.096724187	20,389
2017	Feb-17	3,724	2,897	4,960	11,581	2.096724187	24,282
2017	Mar-17	1,837	2,045	1,219	5,101	2.096724187	10,695
2017	Apr-17	2,562	2,136	1,205	5,903	2.096724187	12,377
2017	May-17	1,435	3,263	3,350	8,048	2.096724187	16,874
2017	Jun-17	4,260	1,955	4,475	10,690	2.096724187	22,414
2017	Jul-17	2,442	4,839	4,695	11,976	2.096724187	25,110
2017	Aug-17	1,692	4,703	2,555	8,950	2.096724187	18,766
2017	Sep-17	3,440	2,598	4,261	10,299	2.096724187	21,594

Appendix Figure 2. Screenshot of CM-SAM Model (Energy & Carbon Assessment Tool)

Whilst this tool provides an easy to use, intuitive, platform for users to assess energy and carbon emissions, it is not without its limitations. Firstly, the model is limited to the five energy groups previously stated and whilst this covers most fuel types, the use is limited to the number of sub-sections available. For example, if a company were to use four different types of liquid fuels (e.g., petrol, diesel, fuel oil, and kerosene), the model only allows for three liquid fuel types to be entered and so the user would be limited to reporting on three out of four fuels, therefore omitted vital information. A simple solution to this limitation would be to increase the number of options for inputting multiple fuel types, however, the researcher felt that a balance must be achieved and presenting too many options would create a complex and chaotic tool, taking away from the key criteria of developing an intuitive, easy to use tool for SMEs.

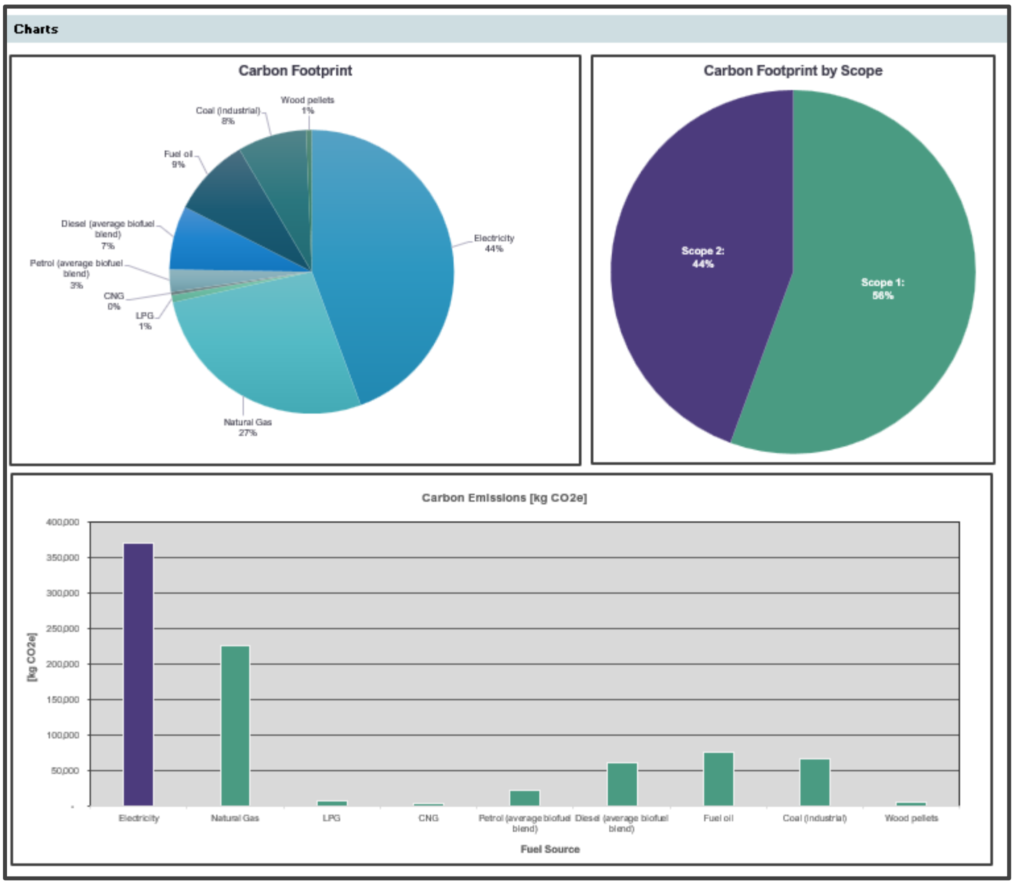
The second limitation comes when future conversion factors are released by the UK government, as the model only supports factors from 2015 – 2022. To overcome this limitation, the researcher decided to forecast future emissions based on historic data, however, limitations are again reached when trying to predict future energy systems and the rate of decarbonisation in the UK's national grid.

The third limitation to the energy and carbon analysis tool presents itself when a user wishes to submit data multiple meters or systems for the same fuel type (e.g., natural gas), but with different billing units (e.g., kWh & cubic meters). The model only allows for one unit selection per sub-section, and so the user would need to use two sub-sections to submit data for one fuel type, reducing the number of available sub-sections.

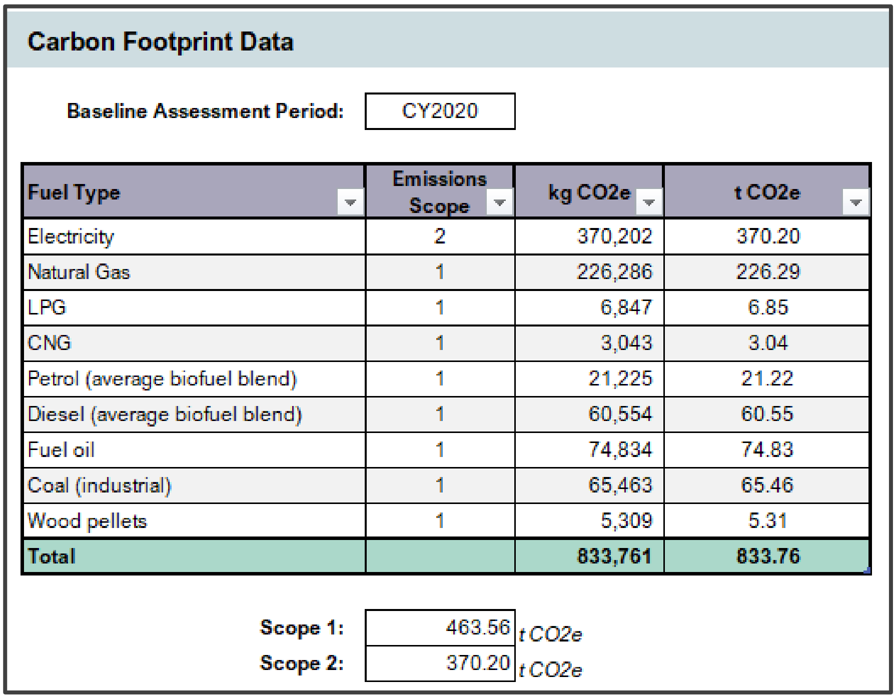
TOOL 2: CARBON FOOTPRINT VISUALISATION

The second tool provided is an extension to tool 1 (energy & carbon analysis) and is used to visualise the results of the baseline carbon assessment. Little to no input is required here from the user, unless any formatting changes are required, as the tool draws on the outputs of tool 1, auto-generating a series of charts and graphical figures to represent the data inputted (see Appendix Figure 3). The tool provides the user with simple but effective charts that can be used within annual reporting. In addition to the charts presented, the tool also provides a summary table of the emissions for the baseline carbon assessment and computes both scope 1 & 2 emissions. The tool is limited to visualisations of the baseline assessment period selected and can only present data for that one period.

Appendix D – Carbon Management Instruments



Appendix Figure 3. Screenshot of CM-SAM Model (Carbon Footprint Visualisation Tool)



Carbon Footprint Data

Baseline Assessment Period: CY2020

Fuel Type	Emissions Scope	kg CO2e	t CO2e
Electricity	2	370,202	370.20
Natural Gas	1	226,286	226.29
LPG	1	6,847	6.85
CNG	1	3,043	3.04
Petrol (average biofuel blend)	1	21,225	21.22
Diesel (average biofuel blend)	1	60,554	60.55
Fuel oil	1	74,834	74.83
Coal (industrial)	1	65,463	65.46
Wood pellets	1	5,309	5.31
Total		**833,761**	**833.76**

Scope 1: 463.56 *t CO2e*
Scope 2: 370.20 *t CO2e*

Appendix Figure 4. Screenshot of CM-SAM Model (Carbon Footprint Visualisation Tool)

TOOL 3: BUSINESS AS USUAL – EMISSIONS FORECAST

The third tool available to users is again linked to tool 1 (energy & carbon analysis) and provides users with a business-as-usual (BAU) emissions forecast. As with the carbon footprint visualisation tool, the forecasting tool uses data inputted to auto-generate a BAU emissions forecast. An exponential smoothing technique is used to predict future emissions based on historic data. This technique is a time series forecasting method used for univariate data [2], that assigns a weighting method to historic data. More recent data points have a higher weighting to represent a greater significance and provide a more realistic forecast. The specific exponential smoothing technique used within the tool is the Holt Winters seasonal method, the additive variation (AAA) (Holt, 1957; Winters, 1960). This specific variant of the technique not only applies a higher weighting to more recent data, but also introduces the parameter of seasonality (NIST/SEMATECH, 2022). This is an important parameter to consider if forecasting the energy use of businesses in the UK, due to the four-season climate typically affecting the energy consumption of UK-based SMEs. It is common for commercial and domestic buildings to use more energy during the winter season as heating is required, however, this is not exclusive to all companies, and some may see an increase in energy consumption during the summer, as an increase in operations could outweigh the energy required for heating.

The tool allows users to visualise predicted future emissions based on historic data, allowing for a greater understanding of how the business has performed over previous years. This information on future emissions could prove useful when looking to develop a carbon reduction plan during Phase 2 of the proposed CM framework.

Despite the benefits of forecasting emissions, there are several limitations to be aware of. Firstly, the forecasting model will only be able to predict future emissions based on data provided, therefore less data available will result in a less accurate forecast and will not be able to account for annual fluctuations in business performance. Furthermore, it is uncertain as to the speed of decarbonisation of

---

[2] *Univariate time series data refers to a set of data that consists of single observation that is consecutively recorded over a series of equal time increments (e.g., monthly energy data)* (NIST/SEMATECH, 2022).

national energy systems, meaning that a large variance can be placed on emissions occurring from grid-procured fuels (e.g., electricity and natural gas).

TOOL 4: CRM FEASIBILITY MODEL

During phase two of the proposed systematic framework (CMF-V3), the CM-SAM is again available to provide support to the user if a detailed analysis of carbon reduction measures (CRM) is required. The fourth tool embedded within the model, allows a user to assess the feasibility of certain predefined CRMs. The CRM feasibility tool incorporates a comprehensive financial analysis model, with the additional capability of predicting carbon savings.

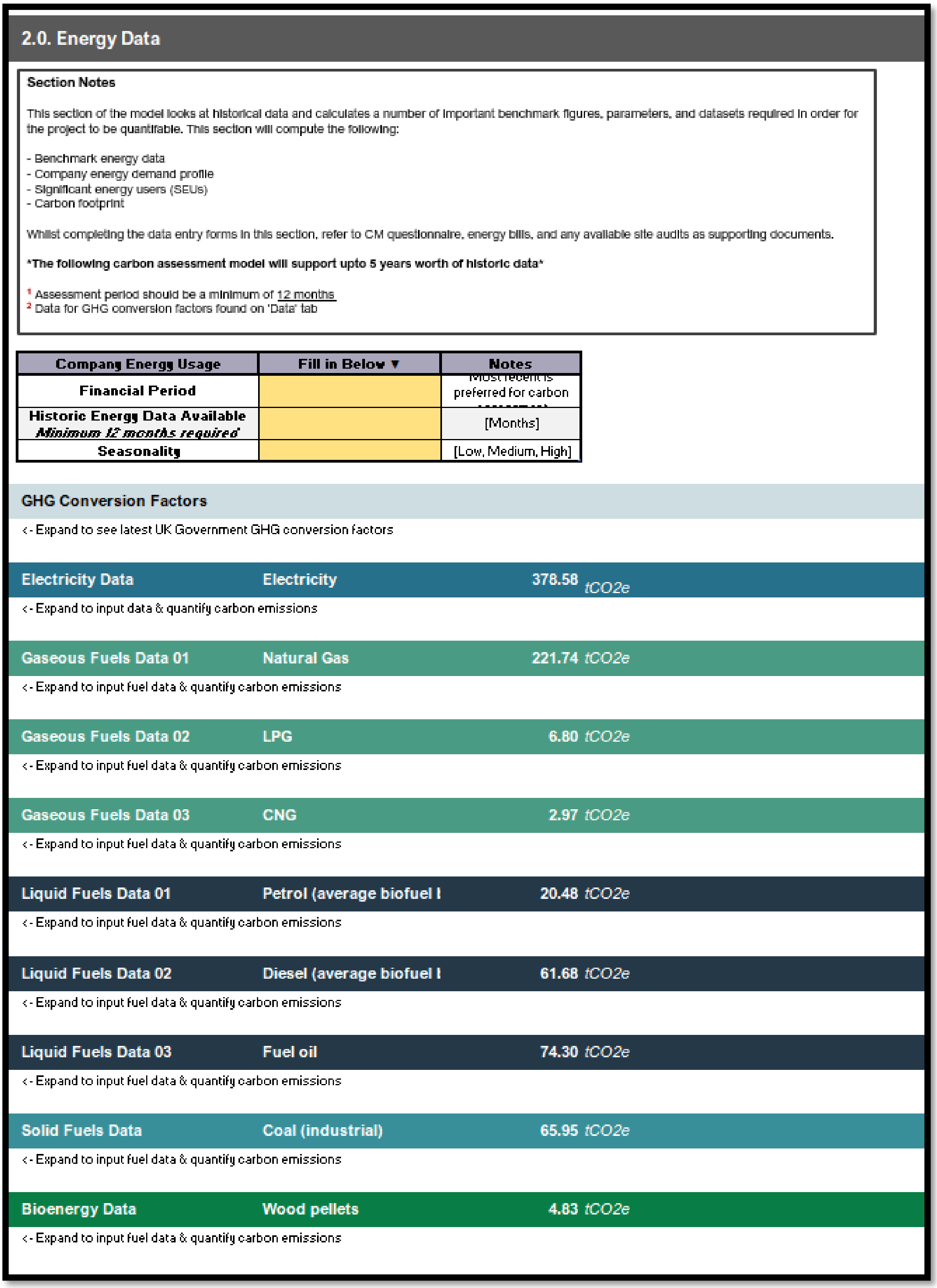
It is a semi-automated tool that can be used to estimate energy savings or generation (depending on the type of CRM), determine the predicted cost savings using common financial indicators, and calculate the potential emissions savings compared with current systems. The CRM feasibility tool requires more input than the other tools discussed, as it asks the user to determine certain parameters that can be challenging to obtain, such as, capital expenditure (CAPEX) of proposed system, energy prices for varying fuel types, operating & maintenance (O&M) costs, and more. The model assumes certain parameters that are inherent in most businesses, however, if the user wishes to achieve further granularity, assumptions can be adapted to their requirements.

The CRM feasibility model starts with a set of comprehensive assumptions with which substantial input is required, it then computes an income statement, balance sheet, cash flow statement, and supporting schedules. The user is then required to adapt certain parameters (including implementation date, fiscal year end, discount rate, perpetual growth rate, and EBITDA multiple) to calculate the discounted cash flow and produce a set of financial decision indicators (FDIs) (including energy cost savings, payback period, return on investment, net present value, and internal rate of return). Once the FDIs have been computed, the model estimates carbon savings based on assumptions defined, which is then used to compute a marginal abatement cost (measured in £/tCO2e).

Once a financial and carbon analysis of proposed CRMs is completed using the feasibility model, the tool will auto-generate a marginal abatement cost curve (MACC). As discussed in *section 5.7.2 – Phase 2: Business Case* of the proposed CMF-V3, a MAC analysis provides the user with a useful tool to illustrate the economics associated with climate change mitigation (Kesicki, 2011). They are typically used by policymakers to find cost effective solutions to meet emissions reduction targets. In the case of this model, the tool produces a MACC as shown in Appendix Figure 22. The MACC can provide vital information to the user during the development of a carbon reduction plan.

As previously suggested the tool is limited by the accuracy of data and the effort involved from the user. Furthermore, the analysis is complex in that the user must have prior knowledge or experience in working with financial models, as the tool includes a number of principles typically found in financial modelling. Finally, the MACC generated can prove a powerful decision-making tool, only if the user understands how to read the chart. Whilst the CRM feasibility model discussed is a valuable addition to the instrument, complexities in operation mean that it requires more time and involvement than the intended target user (a UK-based SME) may want to commit to. Especially given the common barriers discussed previously surrounding a common lack of human and financial resources available to businesses of this size.

CM-SAM –Energy Data



2.0. Energy Data

Section Notes

This section of the model looks at historical data and calculates a number of important benchmark figures, parameters, and datasets required in order for the project to be quantifiable. This section will compute the following:

- Benchmark energy data
- Company energy demand profile
- Significant energy users (SEUs)
- Carbon footprint

Whilst completing the data entry forms in this section, refer to CM questionnaire, energy bills, and any available site audits as supporting documents.

The following carbon assessment model will support upto 5 years worth of historic data

[1] Assessment period should be a minimum of 12 months
[2] Data for GHG conversion factors found on 'Data' tab

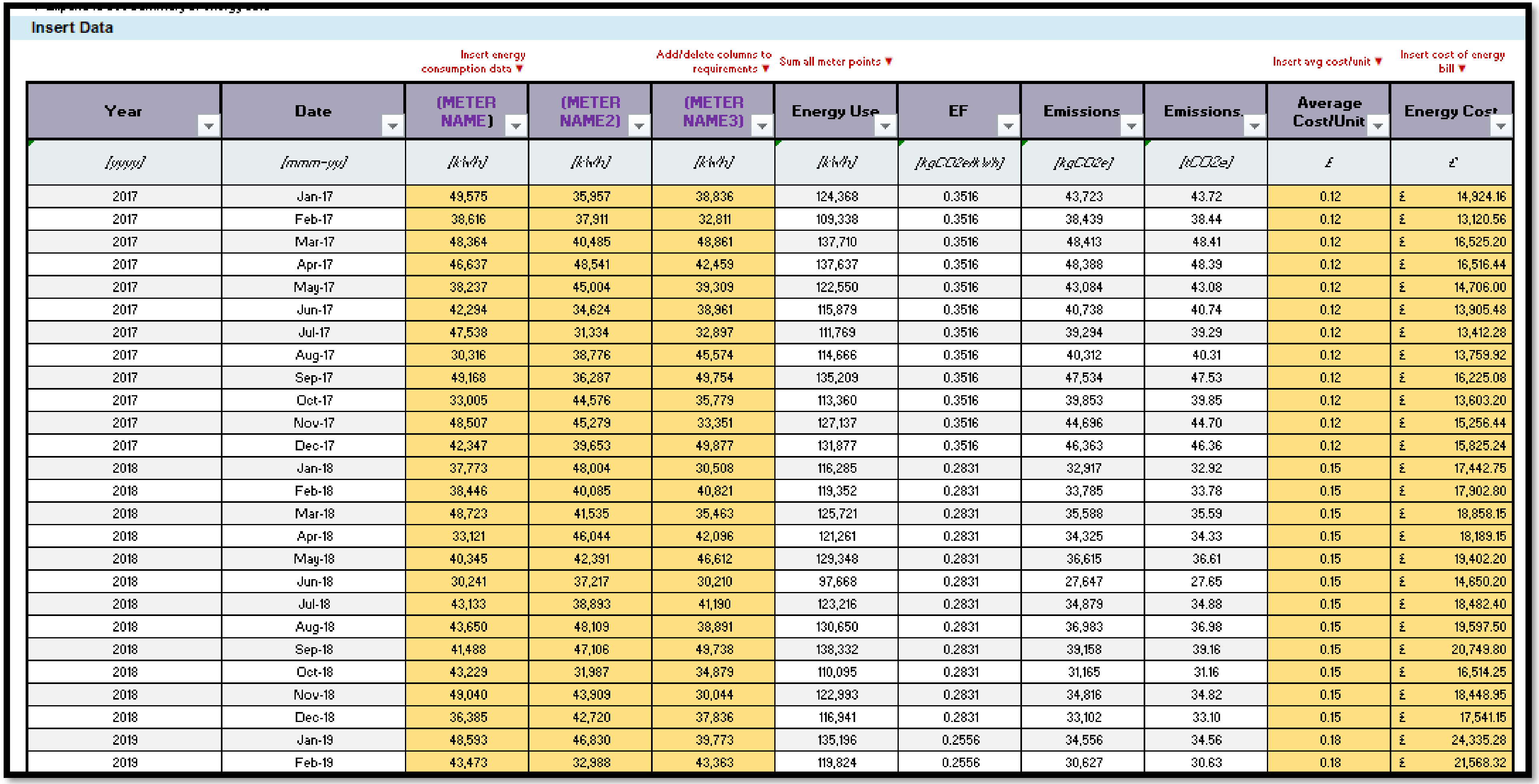
Company Energy Usage	Fill in Below ▼	Notes
Financial Period		Most recent is preferred for carbon
Historic Energy Data Available ***Minimum 12 months required***		[Months]
Seasonality		[Low, Medium, High]

GHG Conversion Factors

<- Expand to see latest UK Government GHG conversion factors

Electricity Data	**Electricity**	**378.58** *tCO2e*
<- Expand to input data & quantify carbon emissions		
Gaseous Fuels Data 01	**Natural Gas**	**221.74** *tCO2e*
<- Expand to input fuel data & quantify carbon emissions		
Gaseous Fuels Data 02	**LPG**	**6.80** *tCO2e*
<- Expand to input fuel data & quantify carbon emissions		
Gaseous Fuels Data 03	**CNG**	**2.97** *tCO2e*
<- Expand to input fuel data & quantify carbon emissions		
Liquid Fuels Data 01	**Petrol (average biofuel l**	**20.48** *tCO2e*
<- Expand to input fuel data & quantify carbon emissions		
Liquid Fuels Data 02	**Diesel (average biofuel l**	**61.68** *tCO2e*
<- Expand to input fuel data & quantify carbon emissions		
Liquid Fuels Data 03	**Fuel oil**	**74.30** *tCO2e*
<- Expand to input fuel data & quantify carbon emissions		
Solid Fuels Data	**Coal (industrial)**	**65.95** *tCO2e*
<- Expand to input fuel data & quantify carbon emissions		
Bioenergy Data	**Wood pellets**	**4.83** *tCO2e*
<- Expand to input fuel data & quantify carbon emissions		

Appendix Figure 5. CM-SAM – Energy Data Sheet 01



Insert Data

Insert energy consumption data ▼

Add/delete columns to requirements ▼

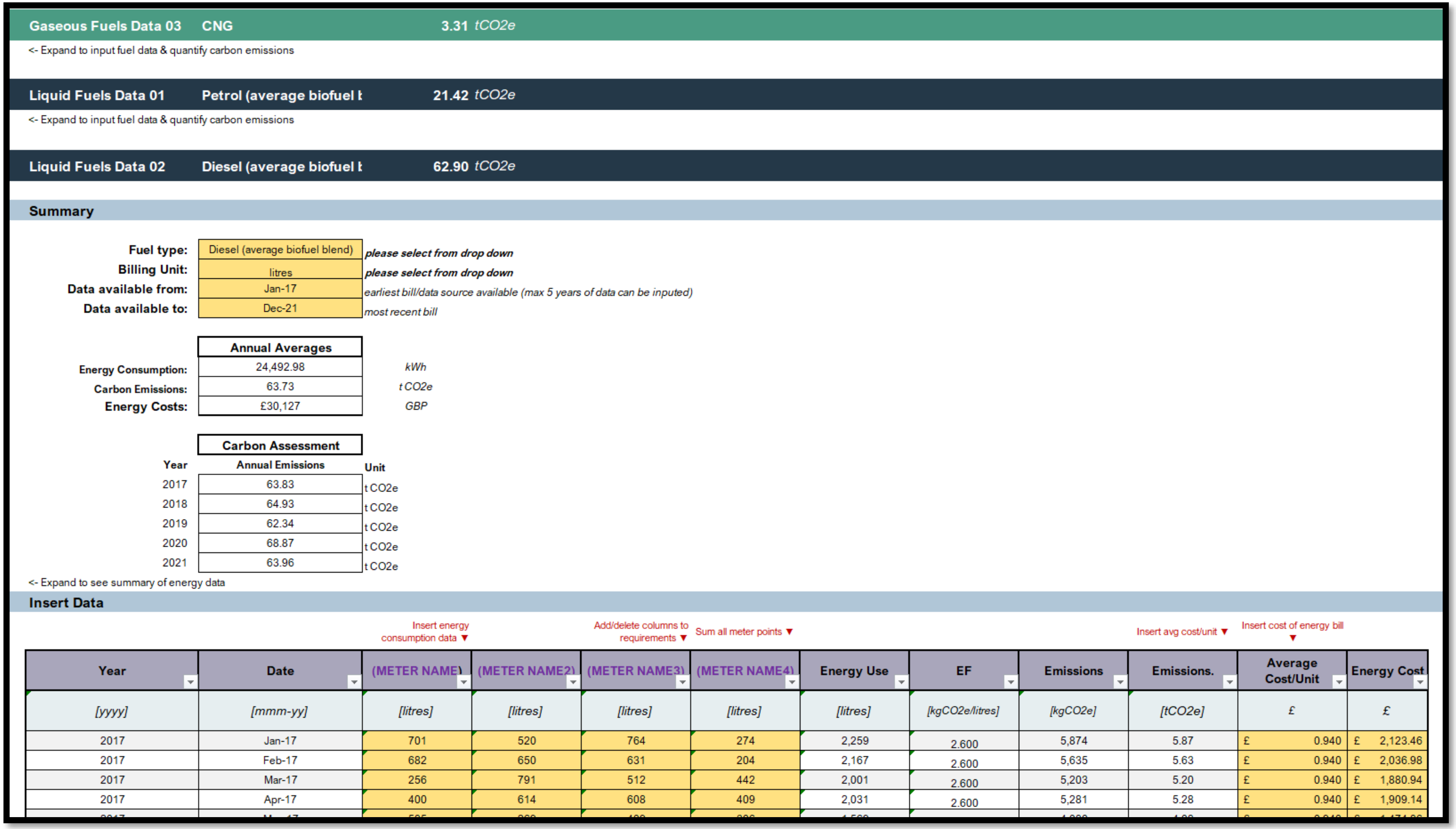
Sum all meter points ▼

Insert avg cost/unit ▼

Insert cost of energy bill ▼

Year	Date	(METER NAME)	(METER NAME2)	(METER NAME3)	Energy Use	EF	Emissions	Emissions	Average Cost/Unit	Energy Cost
[yyyy]	[mmm-yy]	[kWh]	[kWh]	[kWh]	[kWh]	[kgCO2e/kWh]	[kgCO2e]	[tCO2e]	£	£
2017	Jan-17	49,575	35,957	38,836	124,368	0.3516	43,723	43.72	0.12	£ 14,924.16
2017	Feb-17	38,616	37,911	32,811	109,338	0.3516	38,439	38.44	0.12	£ 13,120.56
2017	Mar-17	48,364	40,485	48,861	137,710	0.3516	48,413	48.41	0.12	£ 16,525.20
2017	Apr-17	46,637	48,541	42,459	137,637	0.3516	48,388	48.39	0.12	£ 16,516.44
2017	May-17	38,237	45,004	39,309	122,550	0.3516	43,084	43.08	0.12	£ 14,706.00
2017	Jun-17	42,294	34,624	38,961	115,879	0.3516	40,738	40.74	0.12	£ 13,905.48
2017	Jul-17	47,538	31,334	32,897	111,769	0.3516	39,294	39.29	0.12	£ 13,412.28
2017	Aug-17	30,316	38,776	45,574	114,666	0.3516	40,312	40.31	0.12	£ 13,759.92
2017	Sep-17	49,168	36,287	49,754	135,209	0.3516	47,534	47.53	0.12	£ 16,225.08
2017	Oct-17	33,005	44,576	35,779	113,360	0.3516	39,853	39.85	0.12	£ 13,603.20
2017	Nov-17	48,507	45,279	33,351	127,137	0.3516	44,696	44.70	0.12	£ 15,256.44
2017	Dec-17	42,347	39,653	49,877	131,877	0.3516	46,363	46.36	0.12	£ 15,825.24
2018	Jan-18	37,773	48,004	30,508	116,285	0.2831	32,917	32.92	0.15	£ 17,442.75
2018	Feb-18	38,446	40,085	40,821	119,352	0.2831	33,785	33.78	0.15	£ 17,902.80
2018	Mar-18	48,723	41,535	35,463	125,721	0.2831	35,588	35.59	0.15	£ 18,858.15
2018	Apr-18	33,121	46,044	42,096	121,261	0.2831	34,325	34.33	0.15	£ 18,189.15
2018	May-18	40,345	42,391	46,612	129,348	0.2831	36,615	36.61	0.15	£ 19,402.20
2018	Jun-18	30,241	37,217	30,210	97,668	0.2831	27,647	27.65	0.15	£ 14,650.20
2018	Jul-18	43,133	38,893	41,190	123,216	0.2831	34,879	34.88	0.15	£ 18,482.40
2018	Aug-18	43,650	48,109	38,891	130,650	0.2831	36,983	36.98	0.15	£ 19,597.50
2018	Sep-18	41,488	47,106	49,738	138,332	0.2831	39,158	39.16	0.15	£ 20,749.80
2018	Oct-18	43,229	31,987	34,879	110,095	0.2831	31,165	31.16	0.15	£ 16,514.25
2018	Nov-18	49,040	43,909	30,044	122,993	0.2831	34,816	34.82	0.15	£ 18,448.95
2018	Dec-18	36,385	42,720	37,836	116,941	0.2831	33,102	33.10	0.15	£ 17,541.15
2019	Jan-19	48,593	46,830	39,773	135,196	0.2556	34,556	34.56	0.18	£ 24,335.28
2019	Feb-19	43,473	32,988	43,363	119,824	0.2556	30,627	30.63	0.18	£ 21,568.32

Appendix Figure 6. CM-SAM -Energy Data Sheet 02



Gaseous Fuels Data 03 **CNG** **3.31** *tCO2e*

<- Expand to input fuel data & quantify carbon emissions

Liquid Fuels Data 01 **Petrol (average biofuel b** **21.42** *tCO2e*

<- Expand to input fuel data & quantify carbon emissions

Liquid Fuels Data 02 **Diesel (average biofuel b** **62.90** *tCO2e*

Summary

Fuel type:	Diesel (average biofuel blend)	***please select from drop down***
Billing Unit:	litres	***please select from drop down***
Data available from:	Jan-17	*earliest bill/data source available (max 5 years of data can be inputed)*
Data available to:	Dec-21	*most recent bill*

	Annual Averages	
Energy Consumption:	24,492.98	*kWh*
Carbon Emissions:	63.73	*t CO2e*
Energy Costs:	£30,127	*GBP*

Carbon Assessment

Year	**Annual Emissions**	**Unit**
2017	63.83	t CO2e
2018	64.93	t CO2e
2019	62.34	t CO2e
2020	68.87	t CO2e
2021	63.96	t CO2e

<- Expand to see summary of energy data

Insert Data

Insert energy consumption data ▼

Add/delete columns to requirements ▼

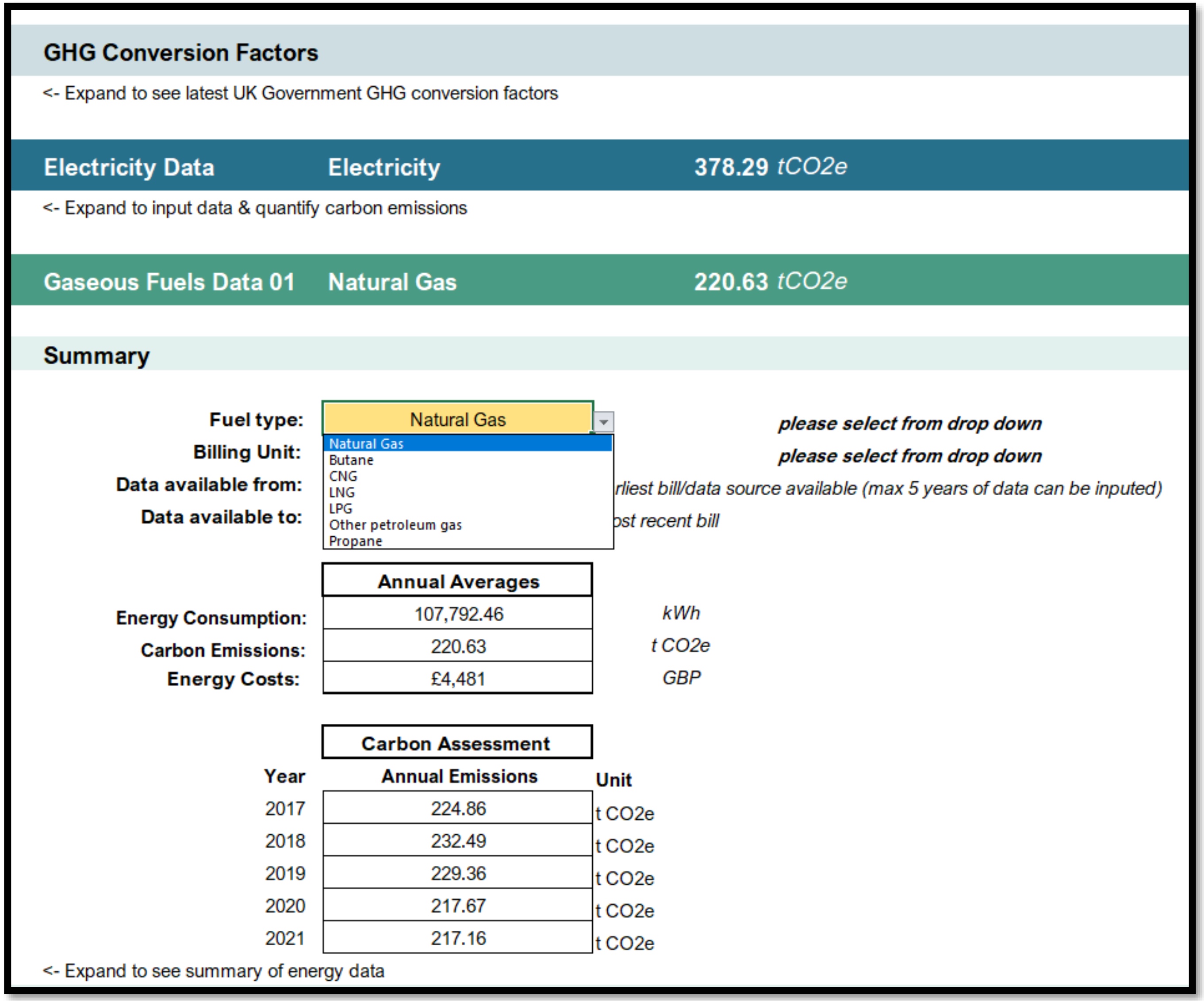
Sum all meter points ▼

Insert avg cost/unit ▼

Insert cost of energy bill ▼

Year	**Date**	**(METER NAME)**	**(METER NAME2)**	**(METER NAME3)**	**(METER NAME4)**	**Energy Use**	**EF**	**Emissions**	**Emissions.**	**Average Cost/Unit**	**Energy Cost**
[yyyy]	*[mmm-yy]*	*[litres]*	*[litres]*	*[litres]*	*[litres]*	*[litres]*	*[kgCO2e/litres]*	*[kgCO2e]*	*[tCO2e]*	*£*	*£*
2017	Jan-17	701	520	764	274	2,259	2.600	5,874	5.87	£ 0.940	£ 2,123.46
2017	Feb-17	682	650	631	204	2,167	2.600	5,635	5.63	£ 0.940	£ 2,036.98
2017	Mar-17	256	791	512	442	2,001	2.600	5,203	5.20	£ 0.940	£ 1,880.94
2017	Apr-17	400	614	608	409	2,031	2.600	5,281	5.28	£ 0.940	£ 1,909.14

Appendix Figure 7. CM-SAM -Energy Data Sheet 03



GHG Conversion Factors

<- Expand to see latest UK Government GHG conversion factors

Electricity Data **Electricity** **378.29** *tCO2e*

<- Expand to input data & quantify carbon emissions

Gaseous Fuels Data 01 **Natural Gas** **220.63** *tCO2e*

Summary

Fuel type: Natural Gas *please select from drop down*

Billing Unit: *please select from drop down*

Data available from: *rliest bill/data source available (max 5 years of data can be inputed)*

Data available to: *ost recent bill*

	Annual Averages	
Energy Consumption:	107,792.46	*kWh*
Carbon Emissions:	220.63	*t CO2e*
Energy Costs:	£4,481	*GBP*

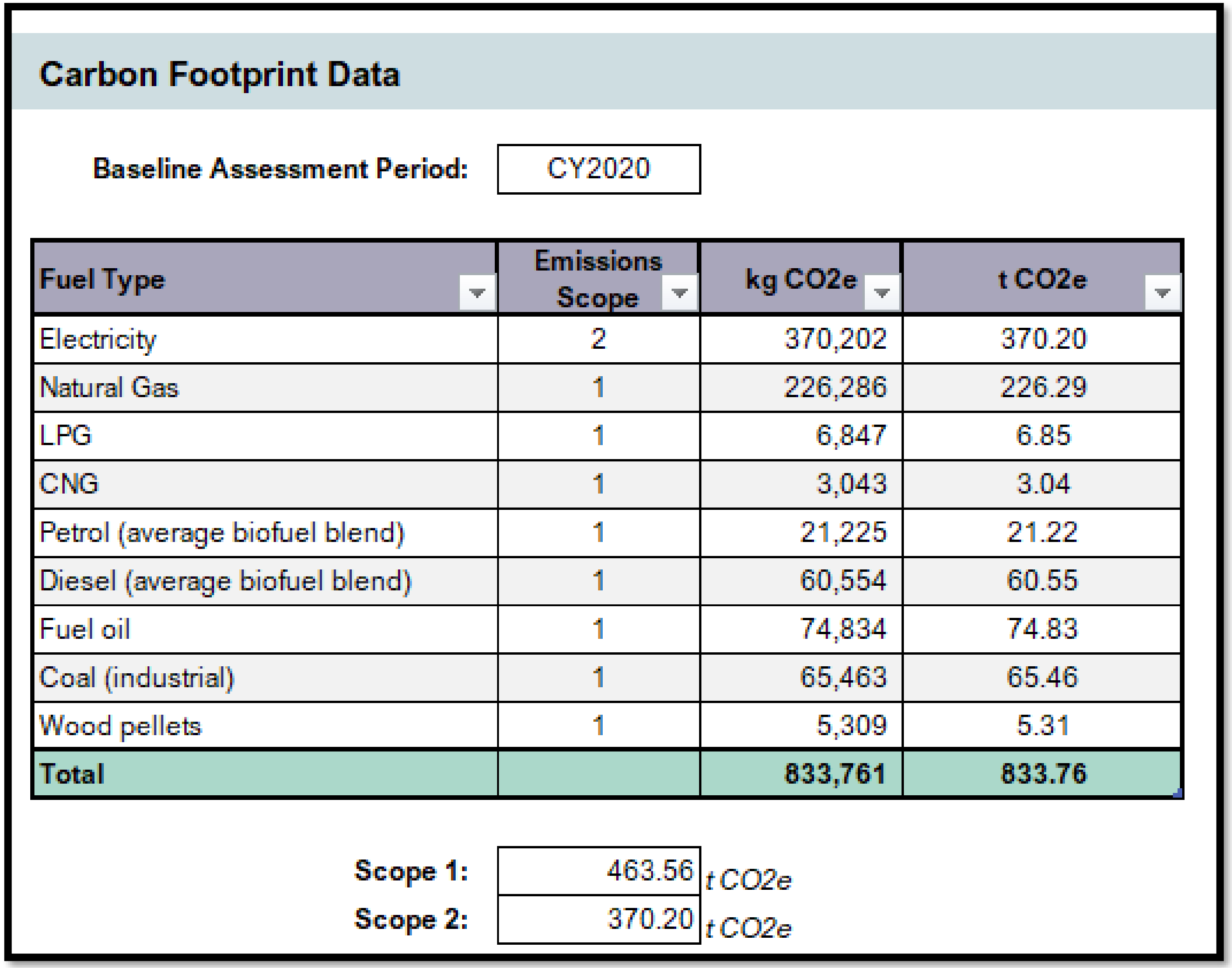
Carbon Assessment

Year	**Annual Emissions**	**Unit**
2017	224.86	t CO2e
2018	232.49	t CO2e
2019	229.36	t CO2e
2020	217.67	t CO2e
2021	217.16	t CO2e

<- Expand to see summary of energy data

Appendix Figure 8. CM-SAM -Energy Data Sheet 03

CM-SAM – Carbon Footprint



Carbon Footprint Data

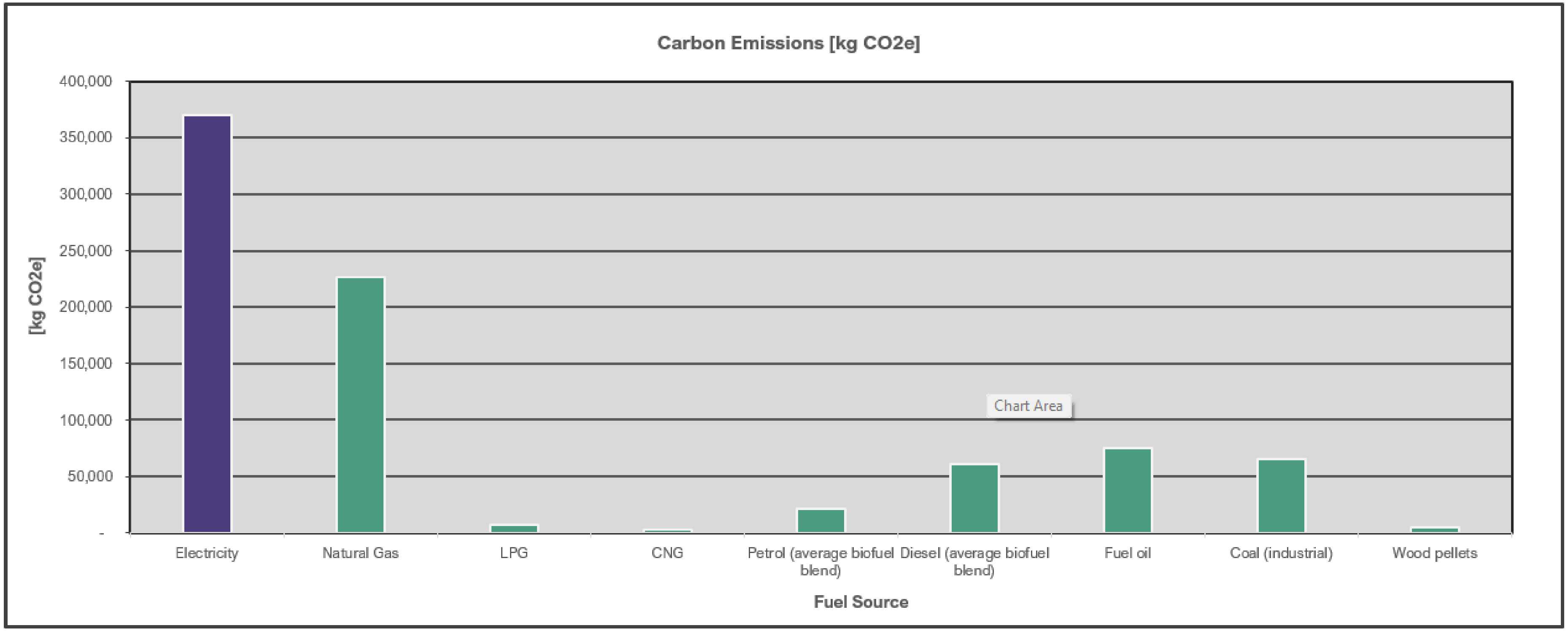
Baseline Assessment Period: CY2020

Fuel Type	Emissions Scope	kg CO2e	t CO2e
Electricity	2	370,202	370.20
Natural Gas	1	226,286	226.29
LPG	1	6,847	6.85
CNG	1	3,043	3.04
Petrol (average biofuel blend)	1	21,225	21.22
Diesel (average biofuel blend)	1	60,554	60.55
Fuel oil	1	74,834	74.83
Coal (industrial)	1	65,463	65.46
Wood pellets	1	5,309	5.31
Total		**833,761**	**833.76**

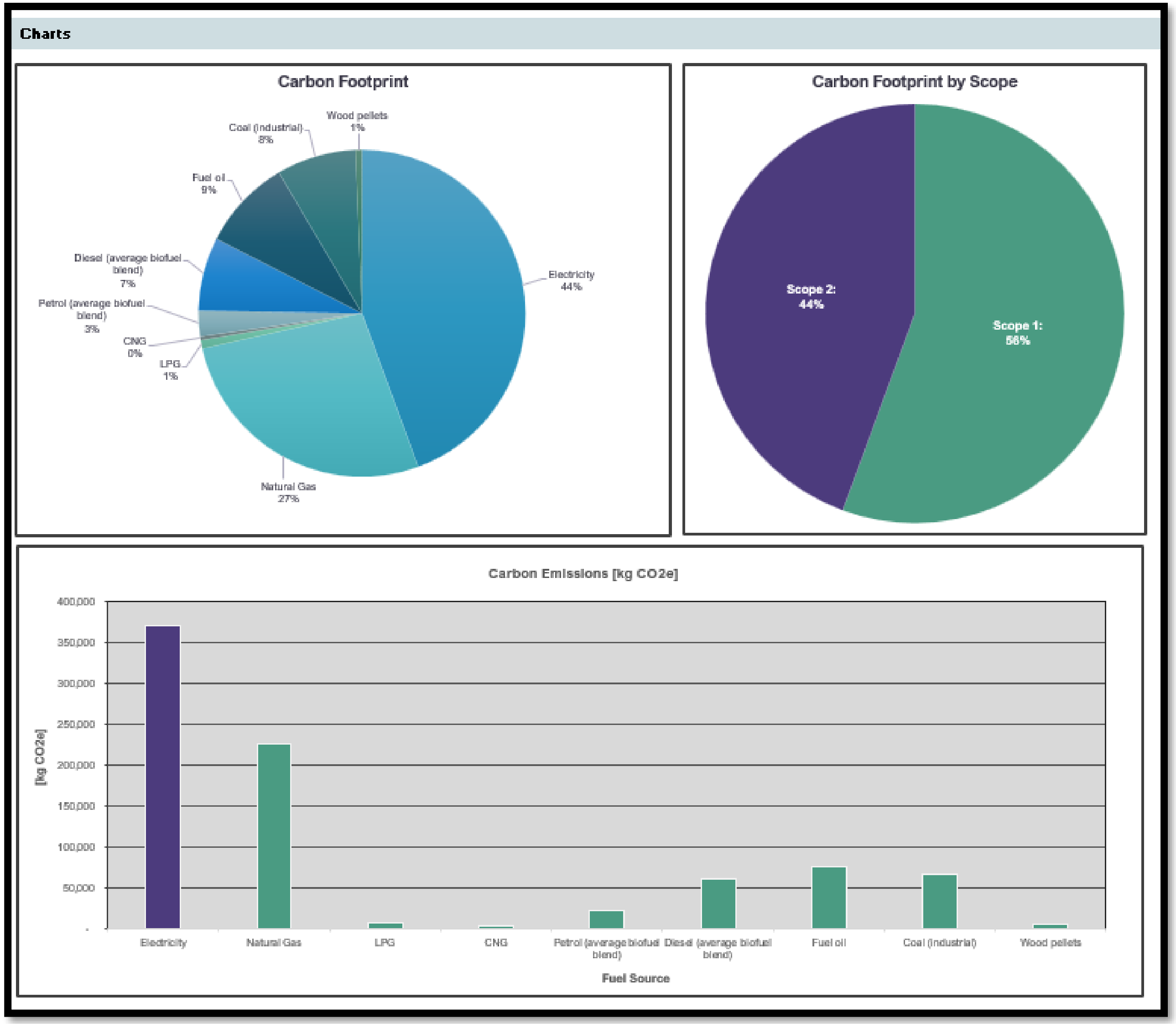
Scope 1: 463.56 *t CO2e*

Scope 2: 370.20 *t CO2e*

Appendix Figure 9. CM-SAM -Carbon Footprint Sheet 01

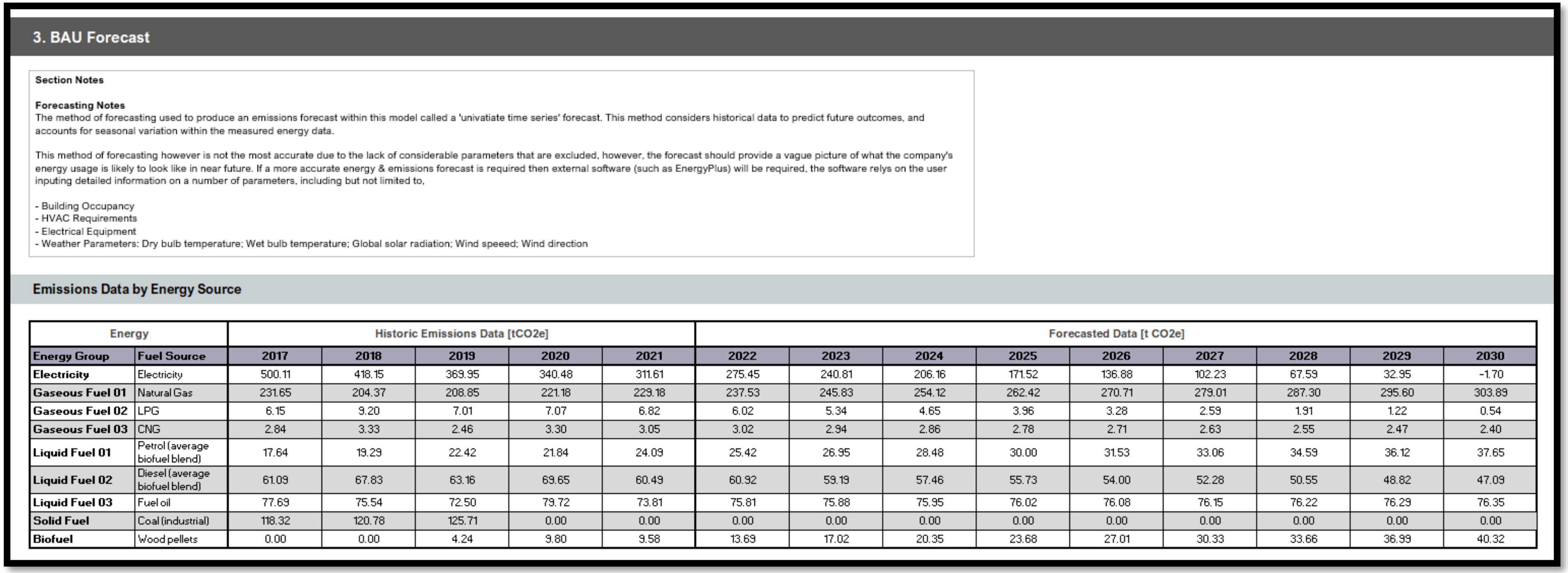


Appendix Figure 10. CM-SAM -Carbon Footprint Sheet 02



Appendix Figure 11. CM-SAM -Carbon Footprint Sheet 03

CM-SAM – Forecasting Analysis



3. BAU Forecast

Section Notes

Forecasting Notes
The method of forecasting used to produce an emissions forecast within this model called a 'univatiate time series' forecast. This method considers historical data to predict future outcomes, and accounts for seasonal variation within the measured energy data.

This method of forecasting however is not the most accurate due to the lack of considerable parameters that are excluded, however, the forecast should provide a vague picture of what the company's energy usage is likely to look like in near future. If a more accurate energy & emissions forecast is required then external software (such as EnergyPlus) will be required, the software relys on the user inputing detailed information on a number of parameters, including but not limited to,

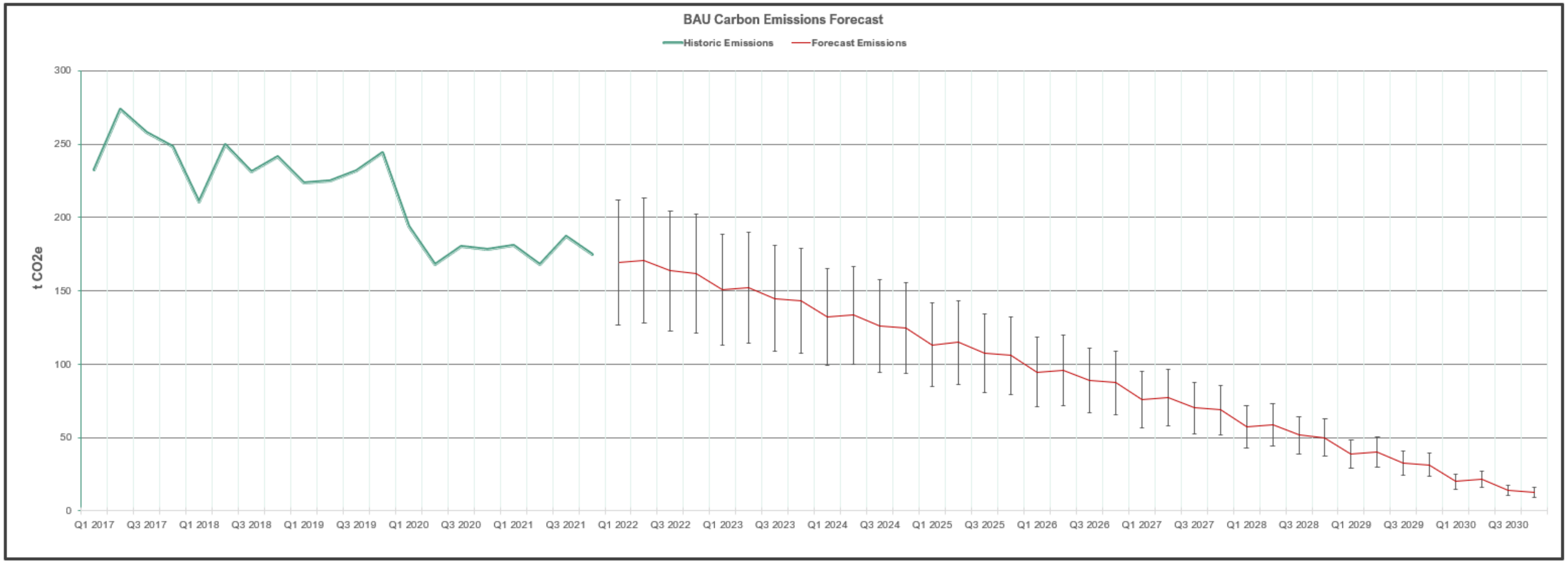
- Building Occupancy
- HVAC Requirements
- Electrical Equipment
- Weather Parameters: Dry bulb temperature; Wet bulb temperature; Global solar radiation; Wind speeed; Wind direction

Emissions Data by Energy Source

Energy		Historic Emissions Data [tCO2e]					Forecasted Data [t CO2e]								
Energy Group	**Fuel Source**	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**	**2023**	**2024**	**2025**	**2026**	**2027**	**2028**	**2029**	**2030**
Electricity	Electricity	500.11	418.15	369.95	340.48	311.61	275.45	240.81	206.16	171.52	136.88	102.23	67.59	32.95	-1.70
Gaseous Fuel 01	Natural Gas	231.65	204.37	208.85	221.18	229.18	237.53	245.83	254.12	262.42	270.71	279.01	287.30	295.60	303.89
Gaseous Fuel 02	LPG	6.15	9.20	7.01	7.07	6.82	6.02	5.34	4.65	3.96	3.28	2.59	1.91	1.22	0.54
Gaseous Fuel 03	CNG	2.84	3.33	2.46	3.30	3.05	3.02	2.94	2.86	2.78	2.71	2.63	2.55	2.47	2.40
Liquid Fuel 01	Petrol (average biofuel blend)	17.64	19.29	22.42	21.84	24.09	25.42	26.95	28.48	30.00	31.53	33.06	34.59	36.12	37.65
Liquid Fuel 02	Diesel (average biofuel blend)	61.09	67.83	63.16	69.65	60.49	60.92	59.19	57.46	55.73	54.00	52.28	50.55	48.82	47.09
Liquid Fuel 03	Fuel oil	77.69	75.54	72.50	79.72	73.81	75.81	75.88	75.95	76.02	76.08	76.15	76.22	76.29	76.35
Solid Fuel	Coal (industrial)	118.32	120.78	125.71	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Biofuel	Wood pellets	0.00	0.00	4.24	9.80	9.58	13.69	17.02	20.35	23.68	27.01	30.33	33.66	36.99	40.32

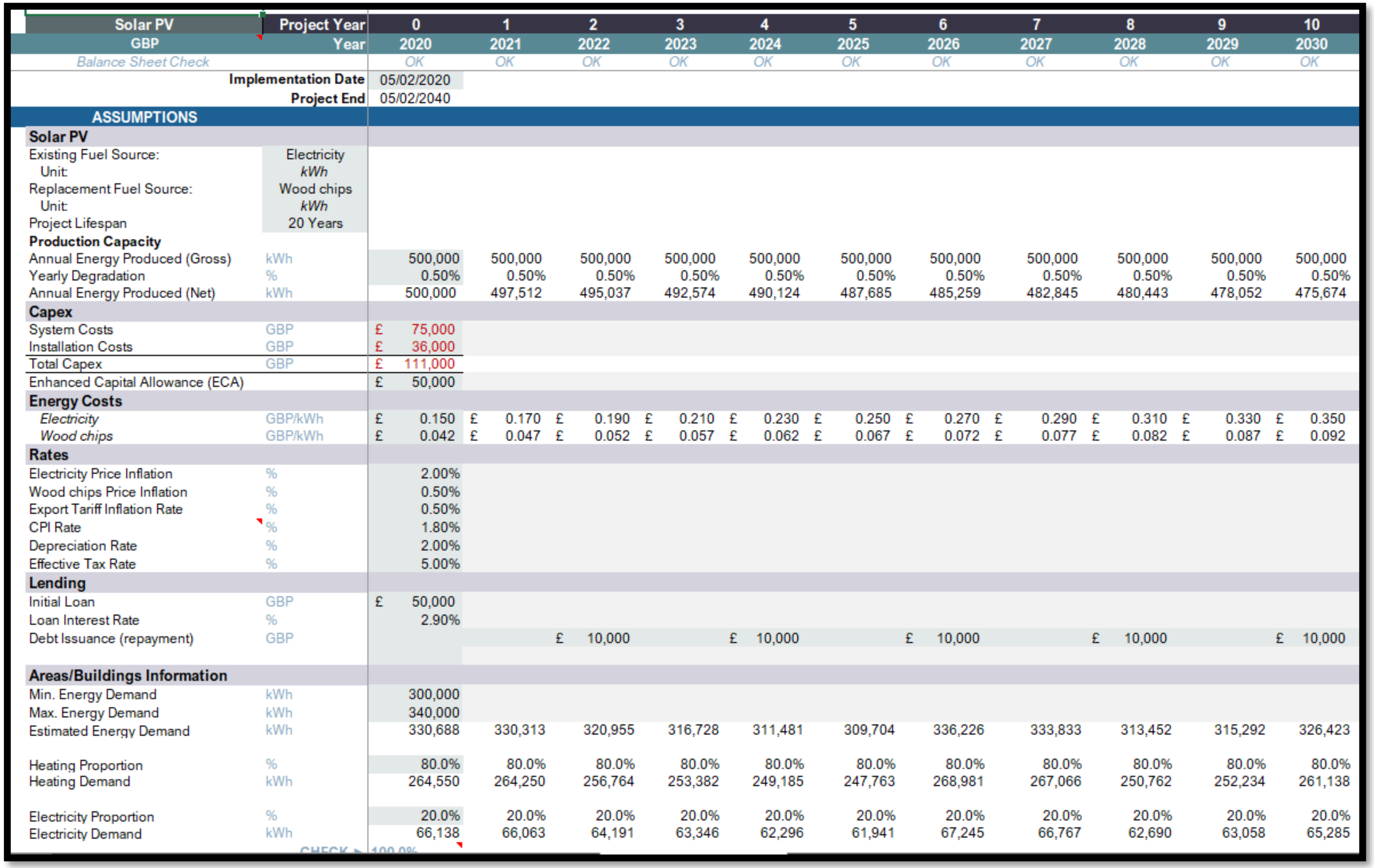
Appendix Figure 12. CM-SAM -Emissions Forecasting Sheet 01

Visualisation of Data Forecasting



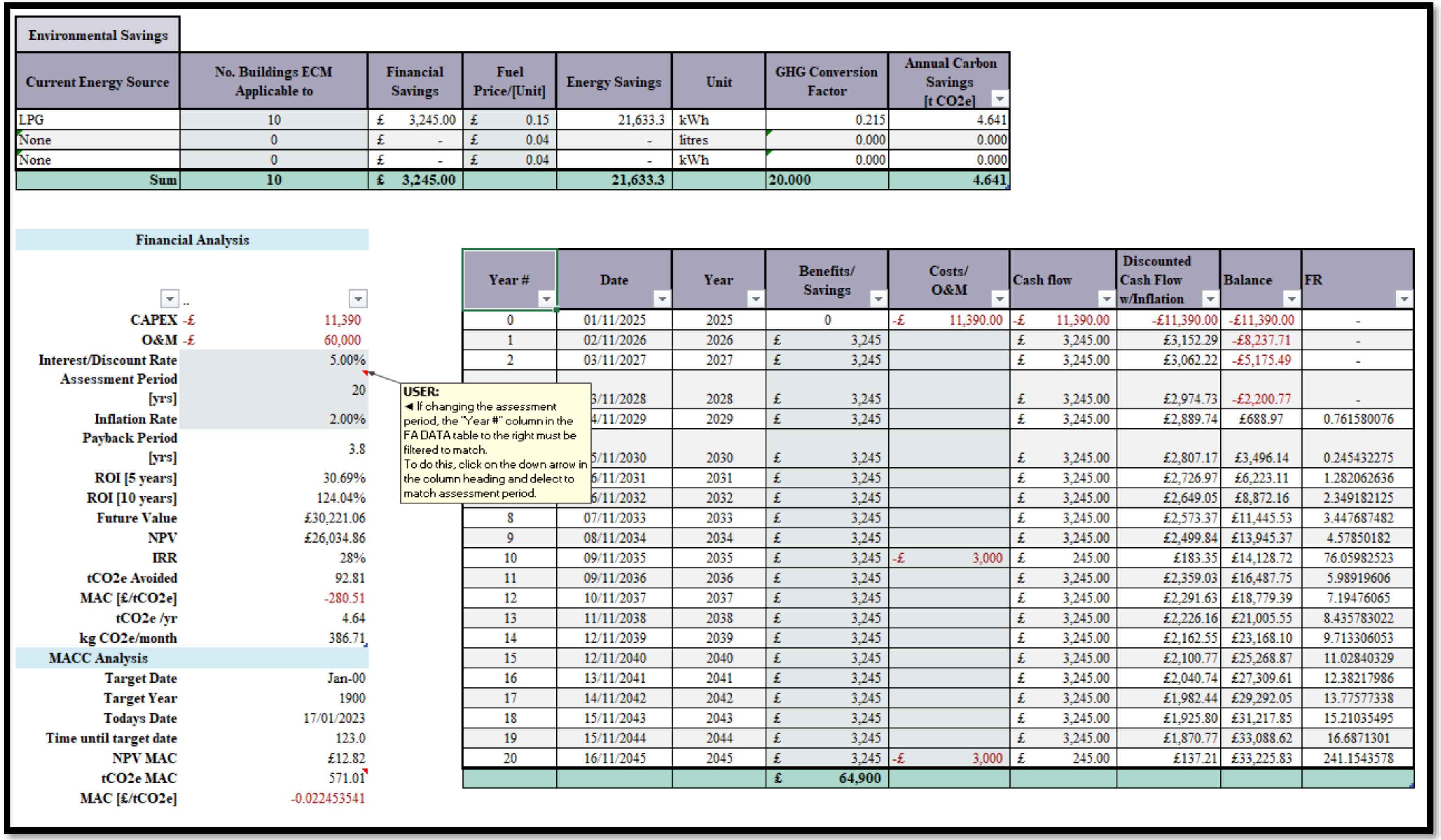
Appendix Figure 13. CM-SAM -Emissions Forecasting Sheet 02

CM-SAM – CRM Financial Analysis



Solar PV	Project Year	0	1	2	3	4	5	6	7	8	9	10
GBP	Year	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
Balance Sheet Check		*OK*	*OK*	*OK*	*OK*	*OK*	*OK*	*OK*	*OK*	*OK*	*OK*	*OK*
	Implementation Date	05/02/2020										
	Project End	05/02/2040										
ASSUMPTIONS												
Solar PV												
Existing Fuel Source:	Electricity											
Unit:	*kWh*											
Replacement Fuel Source:	Wood chips											
Unit:	*kWh*											
Project Lifespan	20 Years											
Production Capacity												
Annual Energy Produced (Gross)	kWh	500,000	500,000	500,000	500,000	500,000	500,000	500,000	500,000	500,000	500,000	500,000
Yearly Degradation	%	0.50%	0.50%	0.50%	0.50%	0.50%	0.50%	0.50%	0.50%	0.50%	0.50%	0.50%
Annual Energy Produced (Net)	kWh	500,000	497,512	495,037	492,574	490,124	487,685	485,259	482,845	480,443	478,052	475,674
Capex												
System Costs	GBP	£ 75,000										
Installation Costs	GBP	£ 36,000										
Total Capex	GBP	£ 111,000										
Enhanced Capital Allowance (ECA)		£ 50,000										
Energy Costs												
Electricity	GBP/kWh	£ 0.150	£ 0.170	£ 0.190	£ 0.210	£ 0.230	£ 0.250	£ 0.270	£ 0.290	£ 0.310	£ 0.330	£ 0.350
Wood chips	GBP/kWh	£ 0.042	£ 0.047	£ 0.052	£ 0.057	£ 0.062	£ 0.067	£ 0.072	£ 0.077	£ 0.082	£ 0.087	£ 0.092
Rates												
Electricity Price Inflation	%	2.00%										
Wood chips Price Inflation	%	0.50%										
Export Tariff Inflation Rate	%	0.50%										
CPI Rate	%	1.80%										
Depreciation Rate	%	2.00%										
Effective Tax Rate	%	5.00%										
Lending												
Initial Loan	GBP	£ 50,000										
Loan Interest Rate	%	2.90%										
Debt Issuance (repayment)	GBP			£ 10,000		£ 10,000		£ 10,000		£ 10,000		£ 10,000
Areas/Buildings Information												
Min. Energy Demand	kWh	300,000										
Max. Energy Demand	kWh	340,000										
Estimated Energy Demand	kWh	330,688	330,313	320,955	316,728	311,481	309,704	336,226	333,833	313,452	315,292	326,423
Heating Proportion	%	80.0%	80.0%	80.0%	80.0%	80.0%	80.0%	80.0%	80.0%	80.0%	80.0%	80.0%
Heating Demand	kWh	264,550	264,250	256,764	253,382	249,185	247,763	268,981	267,066	250,762	252,234	261,138
Electricity Proportion	%	20.0%	20.0%	20.0%	20.0%	20.0%	20.0%	20.0%	20.0%	20.0%	20.0%	20.0%
Electricity Demand	kWh	66,138	66,063	64,191	63,346	62,296	61,941	67,245	66,767	62,690	63,058	65,285
	CHECK ►	100.0%										

Appendix Figure 14. CM-SAM -CRM Financial Analysis 01



Environmental Savings

Current Energy Source	No. Buildings ECM Applicable to	Financial Savings	Fuel Price/[Unit]	Energy Savings	Unit	GHG Conversion Factor	Annual Carbon Savings [t CO2e]
LPG	10	£ 3,245.00	£ 0.15	21,633.3	kWh	0.215	4.641
None	0	£ -	£ 0.04	-	litres	0.000	0.000
None	0	£ -	£ 0.04	-	kWh	0.000	0.000
Sum	10	£ 3,245.00		21,633.3		20.000	4.641

Financial Analysis

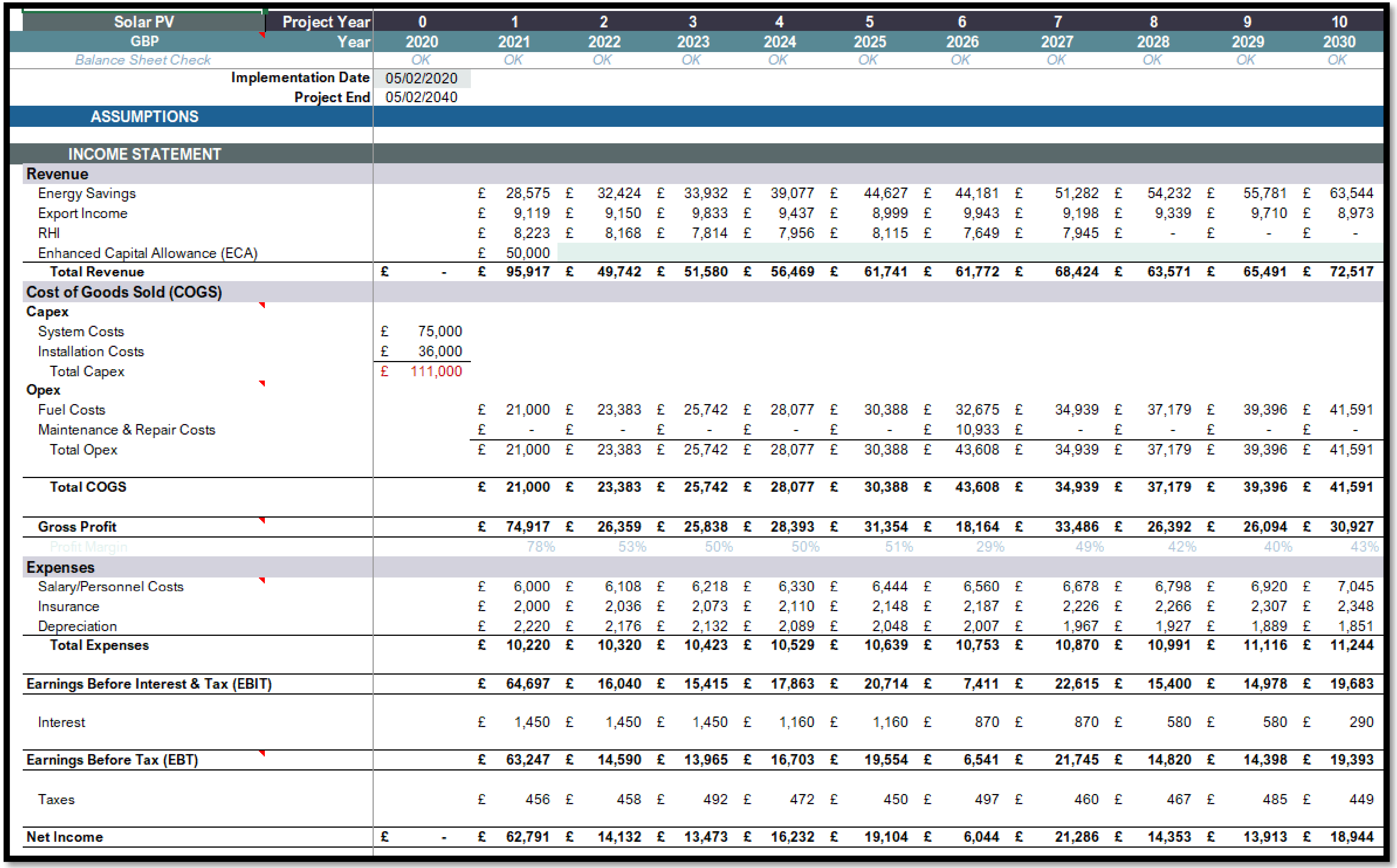
..	
CAPEX	-£ 11,390
O&M	-£ 60,000
Interest/Discount Rate	5.00%
Assessment Period [yrs]	20
Inflation Rate	2.00%
Payback Period [yrs]	3.8
ROI [5 years]	30.69%
ROI [10 years]	124.04%
Future Value	£30,221.06
NPV	£26,034.86
IRR	28%
tCO2e Avoided	92.81
MAC [£/tCO2e]	-280.51
tCO2e /yr	4.64
kg CO2e/month	386.71
MACC Analysis	
Target Date	Jan-00
Target Year	1900
Todays Date	17/01/2023
Time until target date	123.0
NPV MAC	£12.82
tCO2e MAC	571.01
MAC [£/tCO2e]	-0.022453541

USER:
◄ If changing the assessment period, the "Year #" column in the FA DATA table to the right must be filtered to match.
To do this, click on the down arrow in the column heading and delect to match assessment period.

Year #	Date	Year	Benefits/ Savings	Costs/ O&M	Cash flow	Discounted Cash Flow w/Inflation	Balance	FR
0	01/11/2025	2025	0	-£ 11,390.00	-£ 11,390.00	-£11,390.00	-£11,390.00	-
1	02/11/2026	2026	£ 3,245		£ 3,245.00	£3,152.29	-£8,237.71	-
2	03/11/2027	2027	£ 3,245		£ 3,245.00	£3,062.22	-£5,175.49	-
	3/11/2028	2028	£ 3,245		£ 3,245.00	£2,974.73	-£2,200.77	-
	4/11/2029	2029	£ 3,245		£ 3,245.00	£2,889.74	£688.97	0.761580076
	5/11/2030	2030	£ 3,245		£ 3,245.00	£2,807.17	£3,496.14	0.245432275
	6/11/2031	2031	£ 3,245		£ 3,245.00	£2,726.97	£6,223.11	1.282062636
	6/11/2032	2032	£ 3,245		£ 3,245.00	£2,649.05	£8,872.16	2.349182125
8	07/11/2033	2033	£ 3,245		£ 3,245.00	£2,573.37	£11,445.53	3.447687482
9	08/11/2034	2034	£ 3,245		£ 3,245.00	£2,499.84	£13,945.37	4.57850182
10	09/11/2035	2035	£ 3,245	-£ 3,000	£ 245.00	£183.35	£14,128.72	76.05982523
11	09/11/2036	2036	£ 3,245		£ 3,245.00	£2,359.03	£16,487.75	5.98919606
12	10/11/2037	2037	£ 3,245		£ 3,245.00	£2,291.63	£18,779.39	7.19476065
13	11/11/2038	2038	£ 3,245		£ 3,245.00	£2,226.16	£21,005.55	8.435783022
14	12/11/2039	2039	£ 3,245		£ 3,245.00	£2,162.55	£23,168.10	9.713306053
15	12/11/2040	2040	£ 3,245		£ 3,245.00	£2,100.77	£25,268.87	11.02840329
16	13/11/2041	2041	£ 3,245		£ 3,245.00	£2,040.74	£27,309.61	12.38217986
17	14/11/2042	2042	£ 3,245		£ 3,245.00	£1,982.44	£29,292.05	13.77577338
18	15/11/2043	2043	£ 3,245		£ 3,245.00	£1,925.80	£31,217.85	15.21035495
19	15/11/2044	2044	£ 3,245		£ 3,245.00	£1,870.77	£33,088.62	16.6871301
20	16/11/2045	2045	£ 3,245	-£ 3,000	£ 245.00	£137.21	£33,225.83	241.1543578
			£ 64,900					

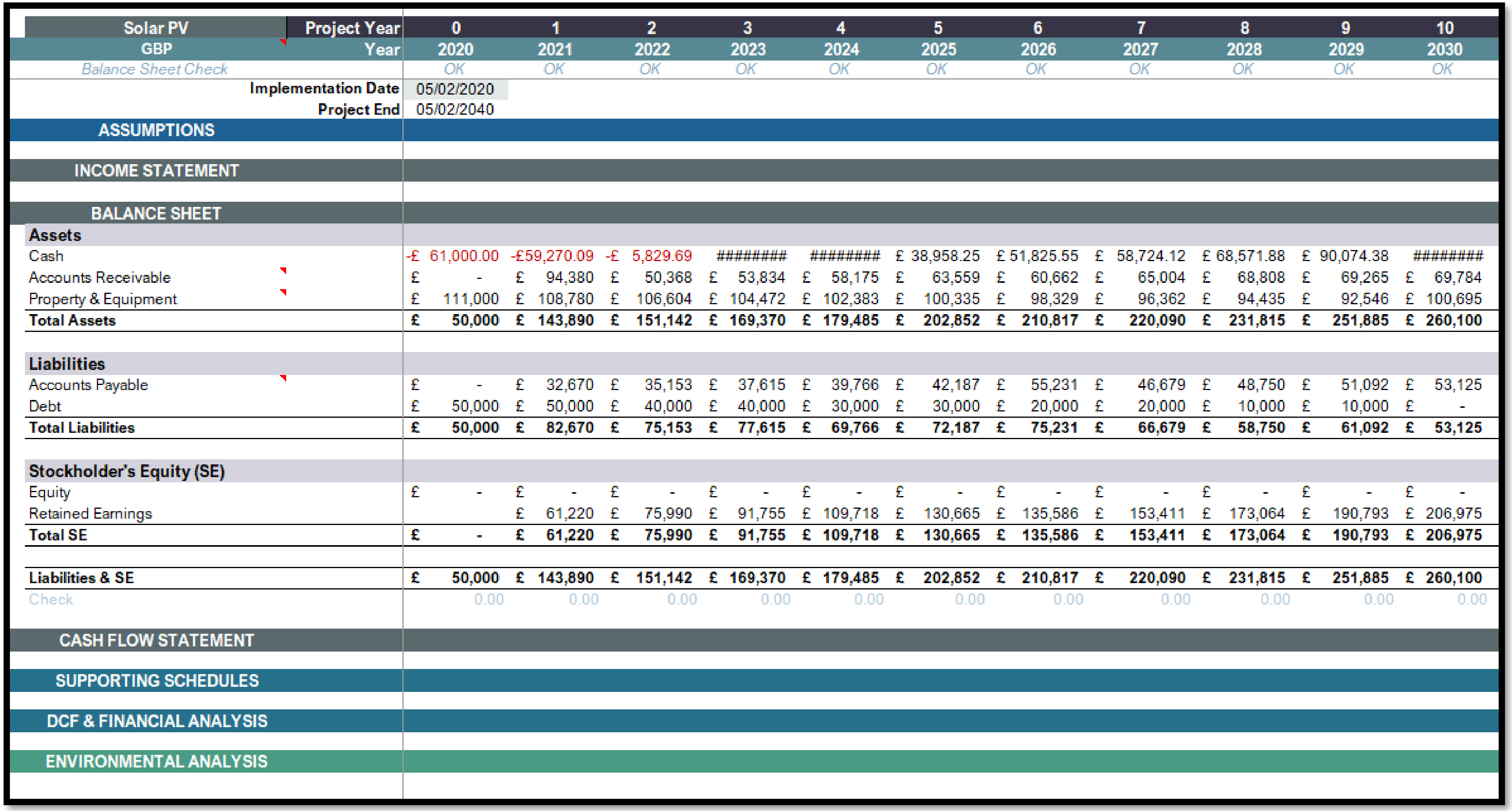
Appendix Figure 15. CM-SAM -CRM Financial Analysis 02

Appendix D – Carbon Management Instruments



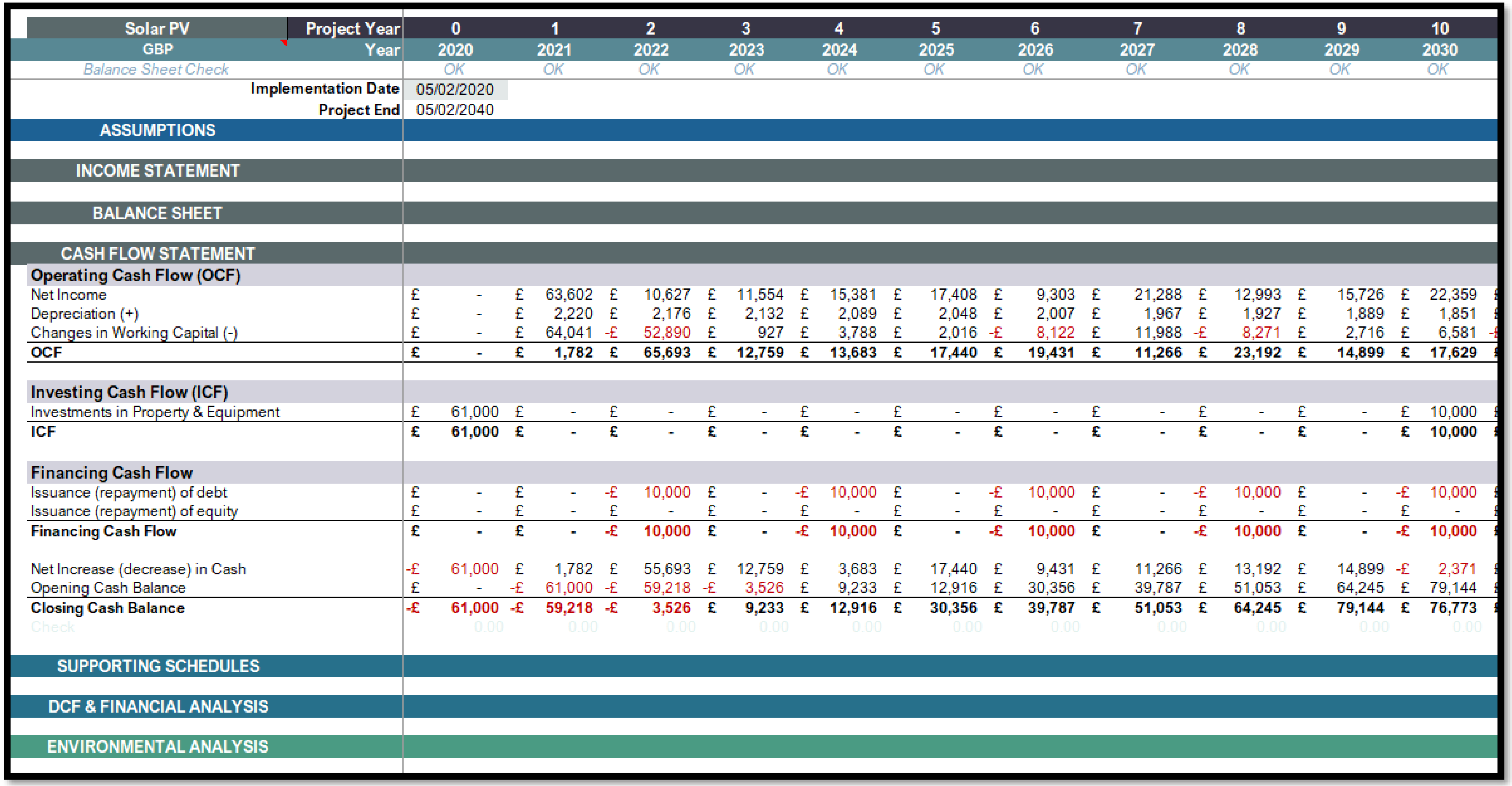
Solar PV	Project Year	0	1	2	3	4	5	6	7	8	9	10
GBP	Year	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
Balance Sheet Check		*OK*	*OK*	*OK*	*OK*	*OK*	*OK*	*OK*	*OK*	*OK*	*OK*	*OK*
	Implementation Date	05/02/2020										
	Project End	05/02/2040										
ASSUMPTIONS												
INCOME STATEMENT												
Revenue												
Energy Savings			£ 28,575	£ 32,424	£ 33,932	£ 39,077	£ 44,627	£ 44,181	£ 51,282	£ 54,232	£ 55,781	£ 63,544
Export Income			£ 9,119	£ 9,150	£ 9,833	£ 9,437	£ 8,999	£ 9,943	£ 9,198	£ 9,339	£ 9,710	£ 8,973
RHI			£ 8,223	£ 8,168	£ 7,814	£ 7,956	£ 8,115	£ 7,649	£ 7,945	£ -	£ -	£ -
Enhanced Capital Allowance (ECA)			£ 50,000									
Total Revenue		**£ -**	**£ 95,917**	**£ 49,742**	**£ 51,580**	**£ 56,469**	**£ 61,741**	**£ 61,772**	**£ 68,424**	**£ 63,571**	**£ 65,491**	**£ 72,517**
Cost of Goods Sold (COGS)												
Capex												
System Costs		£ 75,000										
Installation Costs		£ 36,000										
Total Capex		£ 111,000										
Opex												
Fuel Costs			£ 21,000	£ 23,383	£ 25,742	£ 28,077	£ 30,388	£ 32,675	£ 34,939	£ 37,179	£ 39,396	£ 41,591
Maintenance & Repair Costs			£ -	£ -	£ -	£ -	£ -	£ 10,933	£ -	£ -	£ -	£ -
Total Opex			£ 21,000	£ 23,383	£ 25,742	£ 28,077	£ 30,388	£ 43,608	£ 34,939	£ 37,179	£ 39,396	£ 41,591
Total COGS			**£ 21,000**	**£ 23,383**	**£ 25,742**	**£ 28,077**	**£ 30,388**	**£ 43,608**	**£ 34,939**	**£ 37,179**	**£ 39,396**	**£ 41,591**
Gross Profit			**£ 74,917**	**£ 26,359**	**£ 25,838**	**£ 28,393**	**£ 31,354**	**£ 18,164**	**£ 33,486**	**£ 26,392**	**£ 26,094**	**£ 30,927**
Profit Margin			78%	53%	50%	50%	51%	29%	49%	42%	40%	43%
Expenses												
Salary/Personnel Costs			£ 6,000	£ 6,108	£ 6,218	£ 6,330	£ 6,444	£ 6,560	£ 6,678	£ 6,798	£ 6,920	£ 7,045
Insurance			£ 2,000	£ 2,036	£ 2,073	£ 2,110	£ 2,148	£ 2,187	£ 2,226	£ 2,266	£ 2,307	£ 2,348
Depreciation			£ 2,220	£ 2,176	£ 2,132	£ 2,089	£ 2,048	£ 2,007	£ 1,967	£ 1,927	£ 1,889	£ 1,851
Total Expenses			**£ 10,220**	**£ 10,320**	**£ 10,423**	**£ 10,529**	**£ 10,639**	**£ 10,753**	**£ 10,870**	**£ 10,991**	**£ 11,116**	**£ 11,244**
Earnings Before Interest & Tax (EBIT)			**£ 64,697**	**£ 16,040**	**£ 15,415**	**£ 17,863**	**£ 20,714**	**£ 7,411**	**£ 22,615**	**£ 15,400**	**£ 14,978**	**£ 19,683**
Interest			£ 1,450	£ 1,450	£ 1,450	£ 1,160	£ 1,160	£ 870	£ 870	£ 580	£ 580	£ 290
Earnings Before Tax (EBT)			**£ 63,247**	**£ 14,590**	**£ 13,965**	**£ 16,703**	**£ 19,554**	**£ 6,541**	**£ 21,745**	**£ 14,820**	**£ 14,398**	**£ 19,393**
Taxes			£ 456	£ 458	£ 492	£ 472	£ 450	£ 497	£ 460	£ 467	£ 485	£ 449
Net Income		**£ -**	**£ 62,791**	**£ 14,132**	**£ 13,473**	**£ 16,232**	**£ 19,104**	**£ 6,044**	**£ 21,286**	**£ 14,353**	**£ 13,913**	**£ 18,944**

Appendix Figure 16 CM-SAM -CRM Financial Analysis 03



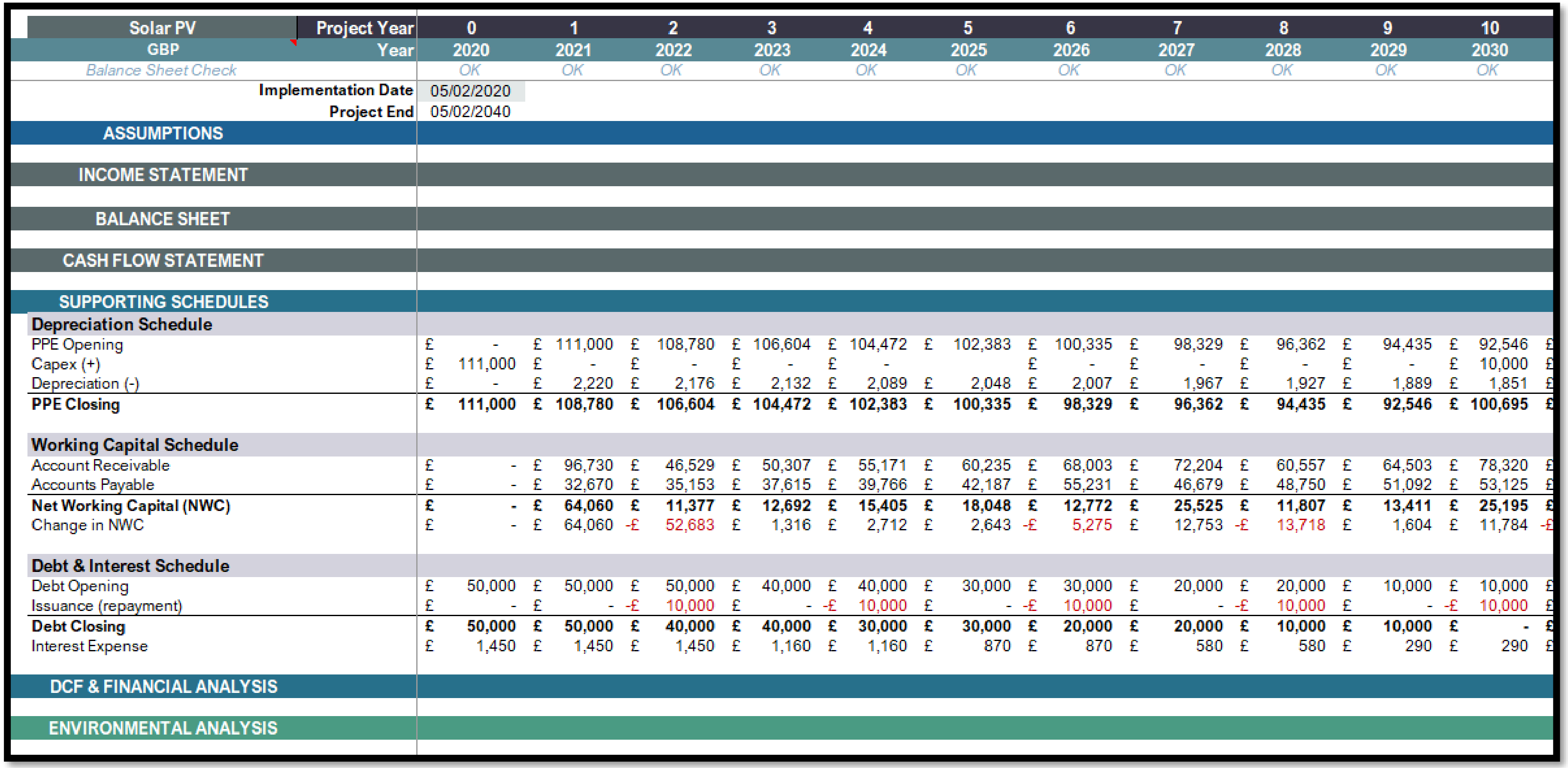
Solar PV	Project Year	0	1	2	3	4	5	6	7	8	9	10
GBP	Year	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
Balance Sheet Check		*OK*	*OK*	*OK*	*OK*	*OK*	*OK*	*OK*	*OK*	*OK*	*OK*	*OK*
	Implementation Date	05/02/2020										
	Project End	05/02/2040										
ASSUMPTIONS												
INCOME STATEMENT												
BALANCE SHEET												
Assets												
Cash		-£ 61,000.00	-£59,270.09	-£ 5,829.69	########	########	£ 38,958.25	£ 51,825.55	£ 58,724.12	£ 68,571.88	£ 90,074.38	########
Accounts Receivable		£ -	£ 94,380	£ 50,368	£ 53,834	£ 58,175	£ 63,559	£ 60,662	£ 65,004	£ 68,808	£ 69,265	£ 69,784
Property & Equipment		£ 111,000	£ 108,780	£ 106,604	£ 104,472	£ 102,383	£ 100,335	£ 98,329	£ 96,362	£ 94,435	£ 92,546	£ 100,695
Total Assets		**£ 50,000**	**£ 143,890**	**£ 151,142**	**£ 169,370**	**£ 179,485**	**£ 202,852**	**£ 210,817**	**£ 220,090**	**£ 231,815**	**£ 251,885**	**£ 260,100**
Liabilities												
Accounts Payable		£ -	£ 32,670	£ 35,153	£ 37,615	£ 39,766	£ 42,187	£ 55,231	£ 46,679	£ 48,750	£ 51,092	£ 53,125
Debt		£ 50,000	£ 50,000	£ 40,000	£ 40,000	£ 30,000	£ 30,000	£ 20,000	£ 20,000	£ 10,000	£ 10,000	£ -
Total Liabilities		**£ 50,000**	**£ 82,670**	**£ 75,153**	**£ 77,615**	**£ 69,766**	**£ 72,187**	**£ 75,231**	**£ 66,679**	**£ 58,750**	**£ 61,092**	**£ 53,125**
Stockholder's Equity (SE)												
Equity		£ -	£ -	£ -	£ -	£ -	£ -	£ -	£ -	£ -	£ -	£ -
Retained Earnings			£ 61,220	£ 75,990	£ 91,755	£ 109,718	£ 130,665	£ 135,586	£ 153,411	£ 173,064	£ 190,793	£ 206,975
Total SE		**£ -**	**£ 61,220**	**£ 75,990**	**£ 91,755**	**£ 109,718**	**£ 130,665**	**£ 135,586**	**£ 153,411**	**£ 173,064**	**£ 190,793**	**£ 206,975**
Liabilities & SE		**£ 50,000**	**£ 143,890**	**£ 151,142**	**£ 169,370**	**£ 179,485**	**£ 202,852**	**£ 210,817**	**£ 220,090**	**£ 231,815**	**£ 251,885**	**£ 260,100**
Check		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
CASH FLOW STATEMENT												
SUPPORTING SCHEDULES												
DCF & FINANCIAL ANALYSIS												
ENVIRONMENTAL ANALYSIS												

Appendix Figure 17. CM-SAM -CRM Financial Analysis 04



Solar PV / Project Year	0	1	2	3	4	5	6	7	8	9	10
GBP / Year	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
Balance Sheet Check	*OK*	*OK*	*OK*	*OK*	*OK*	*OK*	*OK*	*OK*	*OK*	*OK*	*OK*
Implementation Date	05/02/2020										
Project End	05/02/2040										
ASSUMPTIONS											
INCOME STATEMENT											
BALANCE SHEET											
CASH FLOW STATEMENT											
Operating Cash Flow (OCF)											
Net Income	£ -	£ 63,602	£ 10,627	£ 11,554	£ 15,381	£ 17,408	£ 9,303	£ 21,288	£ 12,993	£ 15,726	£ 22,359
Depreciation (+)	£ -	£ 2,220	£ 2,176	£ 2,132	£ 2,089	£ 2,048	£ 2,007	£ 1,967	£ 1,927	£ 1,889	£ 1,851
Changes in Working Capital (-)	£ -	£ 64,041	-£ 52,890	£ 927	£ 3,788	£ 2,016	-£ 8,122	£ 11,988	-£ 8,271	£ 2,716	£ 6,581
OCF	**£ -**	**£ 1,782**	**£ 65,693**	**£ 12,759**	**£ 13,683**	**£ 17,440**	**£ 19,431**	**£ 11,266**	**£ 23,192**	**£ 14,899**	**£ 17,629**
Investing Cash Flow (ICF)											
Investments in Property & Equipment	£ 61,000	£ -	£ -	£ -	£ -	£ -	£ -	£ -	£ -	£ -	£ 10,000
ICF	**£ 61,000**	**£ -**	**£ -**	**£ -**	**£ -**	**£ -**	**£ -**	**£ -**	**£ -**	**£ -**	**£ 10,000**
Financing Cash Flow											
Issuance (repayment) of debt	£ -	£ -	-£ 10,000	£ -	-£ 10,000	£ -	-£ 10,000	£ -	-£ 10,000	£ -	-£ 10,000
Issuance (repayment) of equity	£ -	£ -	£ -	£ -	£ -	£ -	£ -	£ -	£ -	£ -	£ -
Financing Cash Flow	**£ -**	**£ -**	**-£ 10,000**	**£ -**	**-£ 10,000**	**£ -**	**-£ 10,000**	**£ -**	**-£ 10,000**	**£ -**	**-£ 10,000**
Net Increase (decrease) in Cash	-£ 61,000	£ 1,782	£ 55,693	£ 12,759	£ 3,683	£ 17,440	£ 9,431	£ 11,266	£ 13,192	£ 14,899	-£ 2,371
Opening Cash Balance	£ -	-£ 61,000	-£ 59,218	-£ 3,526	£ 9,233	£ 12,916	£ 30,356	£ 39,787	£ 51,053	£ 64,245	£ 79,144
Closing Cash Balance	**-£ 61,000**	**-£ 59,218**	**-£ 3,526**	**£ 9,233**	**£ 12,916**	**£ 30,356**	**£ 39,787**	**£ 51,053**	**£ 64,245**	**£ 79,144**	**£ 76,773**
Check	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
SUPPORTING SCHEDULES											
DCF & FINANCIAL ANALYSIS											
ENVIRONMENTAL ANALYSIS											

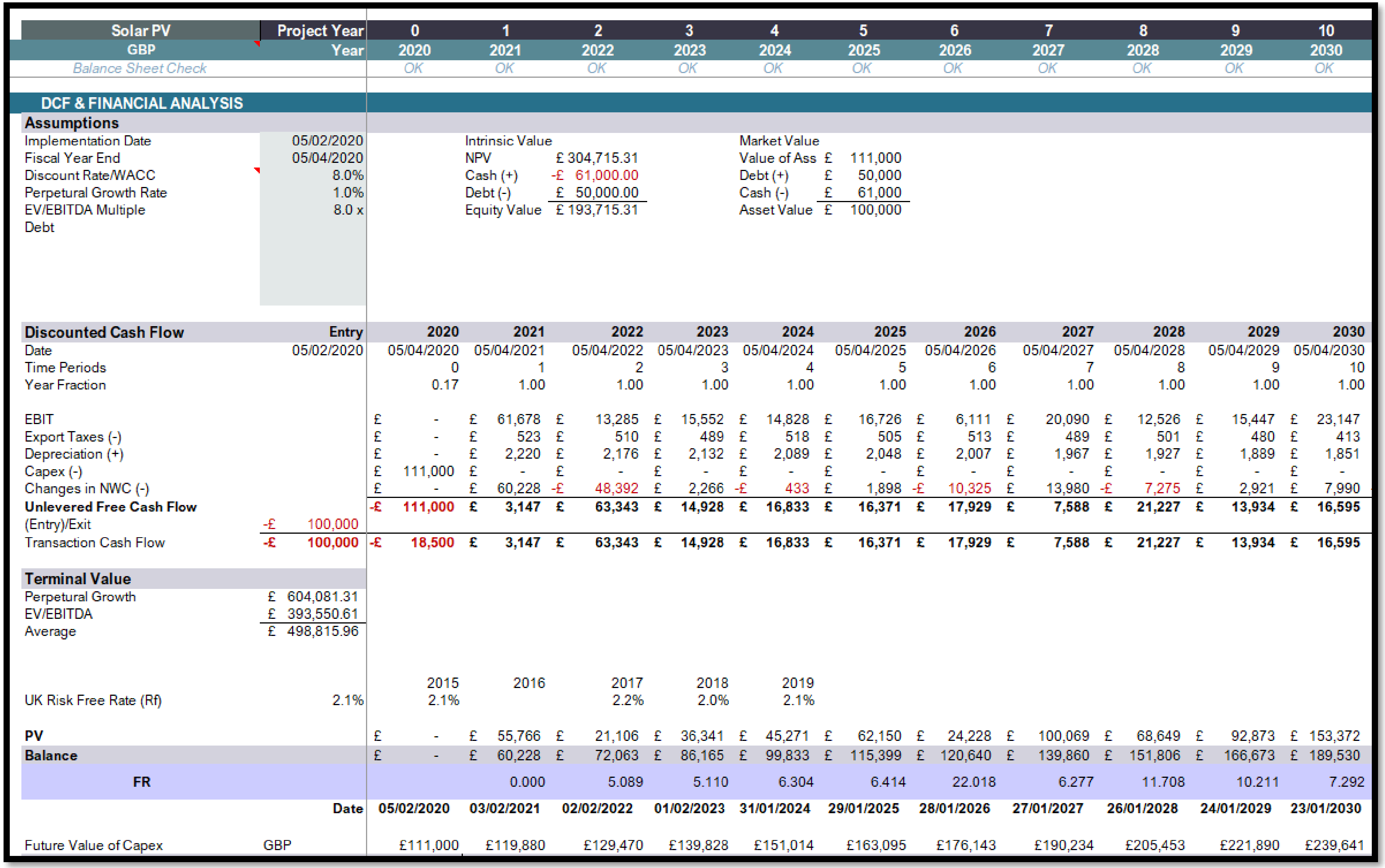
Appendix Figure 18. CM-SAM -CRM Financial Analysis 05



Solar PV	Project Year	0	1	2	3	4	5	6	7	8	9	10
GBP	Year	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
Balance Sheet Check		*OK*	*OK*	*OK*	*OK*	*OK*	*OK*	*OK*	*OK*	*OK*	*OK*	*OK*
	Implementation Date	05/02/2020										
	Project End	05/02/2040										
ASSUMPTIONS												
INCOME STATEMENT												
BALANCE SHEET												
CASH FLOW STATEMENT												
SUPPORTING SCHEDULES												
Depreciation Schedule												
PPE Opening		£ -	£ 111,000	£ 108,780	£ 106,604	£ 104,472	£ 102,383	£ 100,335	£ 98,329	£ 96,362	£ 94,435	£ 92,546
Capex (+)		£ 111,000	£ -	£ -	£ -	£ -		£ -	£ -	£ -	£ -	£ 10,000
Depreciation (-)		£ -	£ 2,220	£ 2,176	£ 2,132	£ 2,089	£ 2,048	£ 2,007	£ 1,967	£ 1,927	£ 1,889	£ 1,851
PPE Closing		**£ 111,000**	**£ 108,780**	**£ 106,604**	**£ 104,472**	**£ 102,383**	**£ 100,335**	**£ 98,329**	**£ 96,362**	**£ 94,435**	**£ 92,546**	**£ 100,695**
Working Capital Schedule												
Account Receivable		£ -	£ 96,730	£ 46,529	£ 50,307	£ 55,171	£ 60,235	£ 68,003	£ 72,204	£ 60,557	£ 64,503	£ 78,320
Accounts Payable		£ -	£ 32,670	£ 35,153	£ 37,615	£ 39,766	£ 42,187	£ 55,231	£ 46,679	£ 48,750	£ 51,092	£ 53,125
Net Working Capital (NWC)		**£ -**	**£ 64,060**	**£ 11,377**	**£ 12,692**	**£ 15,405**	**£ 18,048**	**£ 12,772**	**£ 25,525**	**£ 11,807**	**£ 13,411**	**£ 25,195**
Change in NWC		£ -	£ 64,060	-£ 52,683	£ 1,316	£ 2,712	£ 2,643	-£ 5,275	£ 12,753	-£ 13,718	£ 1,604	£ 11,784
Debt & Interest Schedule												
Debt Opening		£ 50,000	£ 50,000	£ 50,000	£ 40,000	£ 40,000	£ 30,000	£ 30,000	£ 20,000	£ 20,000	£ 10,000	£ 10,000
Issuance (repayment)		£ -	£ -	-£ 10,000	£ -	-£ 10,000	£ -	-£ 10,000	£ -	-£ 10,000	£ -	-£ 10,000
Debt Closing		**£ 50,000**	**£ 50,000**	**£ 40,000**	**£ 40,000**	**£ 30,000**	**£ 30,000**	**£ 20,000**	**£ 20,000**	**£ 10,000**	**£ 10,000**	**£ -**
Interest Expense		£ 1,450	£ 1,450	£ 1,450	£ 1,160	£ 1,160	£ 870	£ 870	£ 580	£ 580	£ 290	£ 290
DCF & FINANCIAL ANALYSIS												
ENVIRONMENTAL ANALYSIS												

Appendix Figure 19. CM-SAM -CRM Financial Analysis 06

Appendix D – Carbon Management Instruments



Solar PV	Project Year	0	1	2	3	4	5	6	7	8	9	10
GBP	Year	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
Balance Sheet Check		*OK*	*OK*	*OK*	*OK*	*OK*	*OK*	*OK*	*OK*	*OK*	*OK*	*OK*

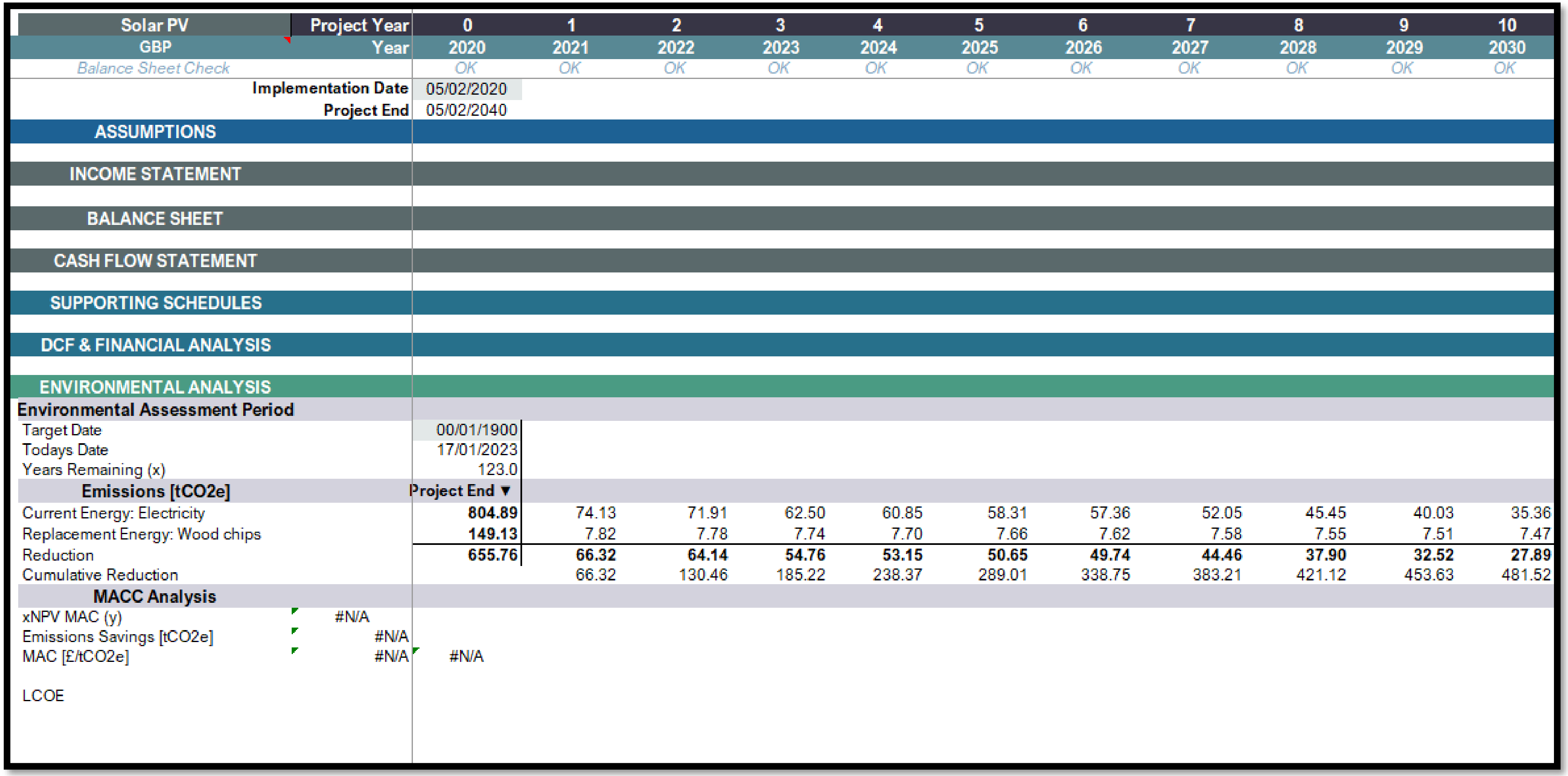
DCF & FINANCIAL ANALYSIS

Assumptions

Implementation Date	05/02/2020	Intrinsic Value		Market Value		
Fiscal Year End	05/04/2020	NPV	£ 304,715.31	Value of Ass	£	111,000
Discount Rate/WACC	8.0%	Cash (+)	-£ 61,000.00	Debt (+)	£	50,000
Perpetural Growth Rate	1.0%	Debt (-)	£ 50,000.00	Cash (-)	£	61,000
EV/EBITDA Multiple	8.0 x	Equity Value	£ 193,715.31	Asset Value	£	100,000
Debt						

Discounted Cash Flow	**Entry**	**2020**	**2021**	**2022**	**2023**	**2024**	**2025**	**2026**	**2027**	**2028**	**2029**	**2030**
Date	05/02/2020	05/04/2020	05/04/2021	05/04/2022	05/04/2023	05/04/2024	05/04/2025	05/04/2026	05/04/2027	05/04/2028	05/04/2029	05/04/2030
Time Periods		0	1	2	3	4	5	6	7	8	9	10
Year Fraction		0.17	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
EBIT		£ -	£ 61,678	£ 13,285	£ 15,552	£ 14,828	£ 16,726	£ 6,111	£ 20,090	£ 12,526	£ 15,447	£ 23,147
Export Taxes (-)		£ -	£ 523	£ 510	£ 489	£ 518	£ 505	£ 513	£ 489	£ 501	£ 480	£ 413
Depreciation (+)		£ -	£ 2,220	£ 2,176	£ 2,132	£ 2,089	£ 2,048	£ 2,007	£ 1,967	£ 1,927	£ 1,889	£ 1,851
Capex (-)		£ 111,000	£ -	£ -	£ -	£ -	£ -	£ -	£ -	£ -	£ -	£ -
Changes in NWC (-)		£ -	£ 60,228	-£ 48,392	£ 2,266	-£ 433	£ 1,898	-£ 10,325	£ 13,980	-£ 7,275	£ 2,921	£ 7,990
Unlevered Free Cash Flow		**-£ 111,000**	**£ 3,147**	**£ 63,343**	**£ 14,928**	**£ 16,833**	**£ 16,371**	**£ 17,929**	**£ 7,588**	**£ 21,227**	**£ 13,934**	**£ 16,595**
(Entry)/Exit	-£ 100,000											
Transaction Cash Flow	**-£ 100,000**	**-£ 18,500**	**£ 3,147**	**£ 63,343**	**£ 14,928**	**£ 16,833**	**£ 16,371**	**£ 17,929**	**£ 7,588**	**£ 21,227**	**£ 13,934**	**£ 16,595**
Terminal Value												
Perpetural Growth	£ 604,081.31											
EV/EBITDA	£ 393,550.61											
Average	£ 498,815.96											
		2015	2016	2017	2018	2019						
UK Risk Free Rate (Rf)	2.1%	2.1%		2.2%	2.0%	2.1%						
PV		£ -	£ 55,766	£ 21,106	£ 36,341	£ 45,271	£ 62,150	£ 24,228	£ 100,069	£ 68,649	£ 92,873	£ 153,372
Balance		£ -	£ 60,228	£ 72,063	£ 86,165	£ 99,833	£ 115,399	£ 120,640	£ 139,860	£ 151,806	£ 166,673	£ 189,530
FR			0.000	5.089	5.110	6.304	6.414	22.018	6.277	11.708	10.211	7.292
	Date	**05/02/2020**	**03/02/2021**	**02/02/2022**	**01/02/2023**	**31/01/2024**	**29/01/2025**	**28/01/2026**	**27/01/2027**	**26/01/2028**	**24/01/2029**	**23/01/2030**
Future Value of Capex	GBP	£111,000	£119,880	£129,470	£139,828	£151,014	£163,095	£176,143	£190,234	£205,453	£221,890	£239,641

Appendix Figure 20. CM-SAM -CRM Financial Analysis 07

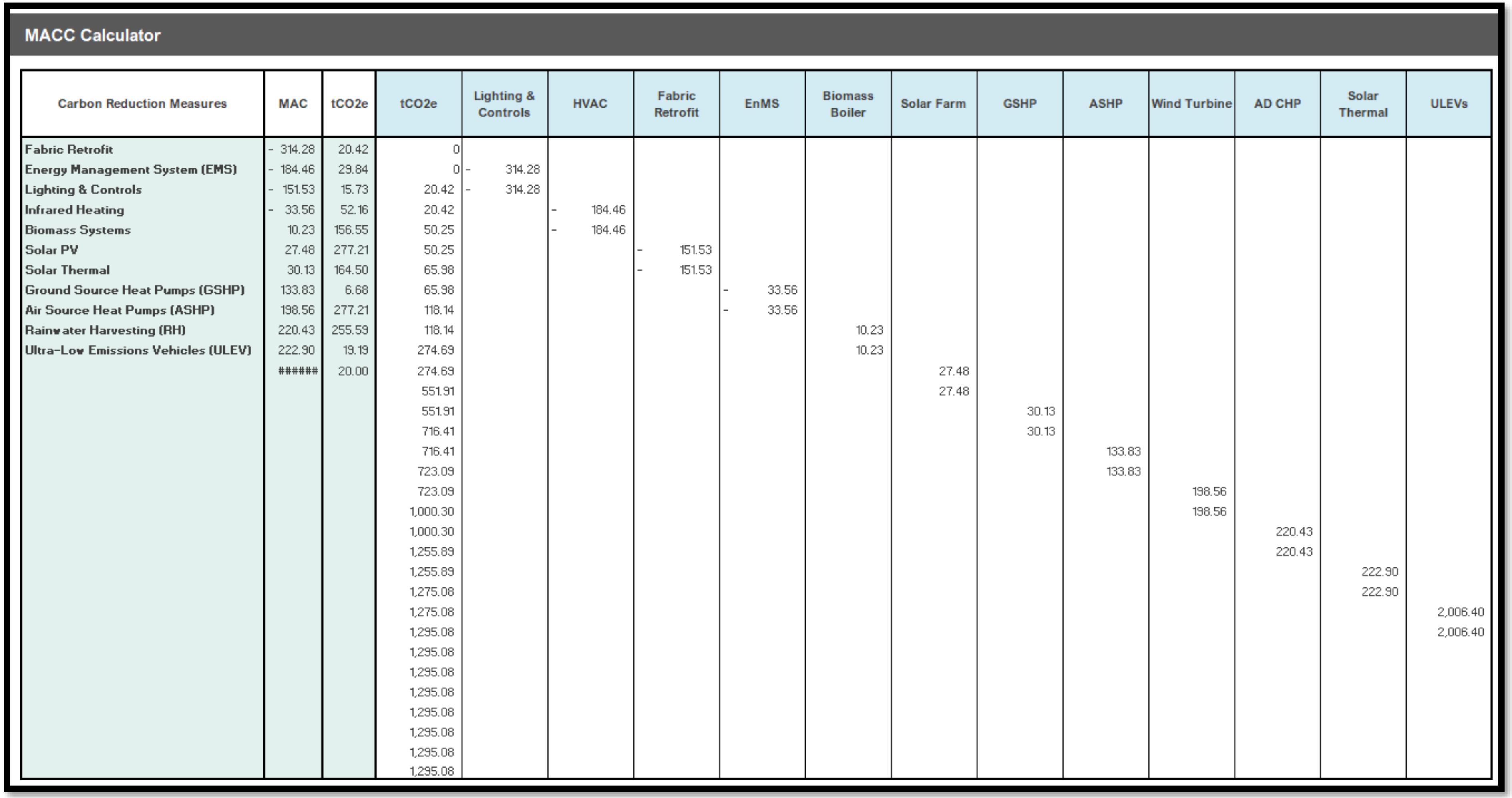


Solar PV	Project Year	0	1	2	3	4	5	6	7	8	9	10
GBP	Year	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
Balance Sheet Check		*OK*	*OK*	*OK*	*OK*	*OK*	*OK*	*OK*	*OK*	*OK*	*OK*	*OK*
	Implementation Date	05/02/2020										
	Project End	05/02/2040										
ASSUMPTIONS												
INCOME STATEMENT												
BALANCE SHEET												
CASH FLOW STATEMENT												
SUPPORTING SCHEDULES												
DCF & FINANCIAL ANALYSIS												
ENVIRONMENTAL ANALYSIS												
Environmental Assessment Period												
Target Date		00/01/1900										
Todays Date		17/01/2023										
Years Remaining (x)		123.0										
Emissions [tCO2e]		**Project End ▼**										
Current Energy: Electricity		**804.89**	74.13	71.91	62.50	60.85	58.31	57.36	52.05	45.45	40.03	35.36
Replacement Energy: Wood chips		**149.13**	7.82	7.78	7.74	7.70	7.66	7.62	7.58	7.55	7.51	7.47
Reduction		**655.76**	**66.32**	**64.14**	**54.76**	**53.15**	**50.65**	**49.74**	**44.46**	**37.90**	**32.52**	**27.89**
Cumulative Reduction			66.32	130.46	185.22	238.37	289.01	338.75	383.21	421.12	453.63	481.52
MACC Analysis												
xNPV MAC (y)	#N/A											
Emissions Savings [tCO2e]	#N/A											
MAC [£/tCO2e]	#N/A	#N/A										
LCOE												

Appendix Figure 21. CM-SAM -CRM Financial Analysis 08

Appendix D – Carbon Management Instruments

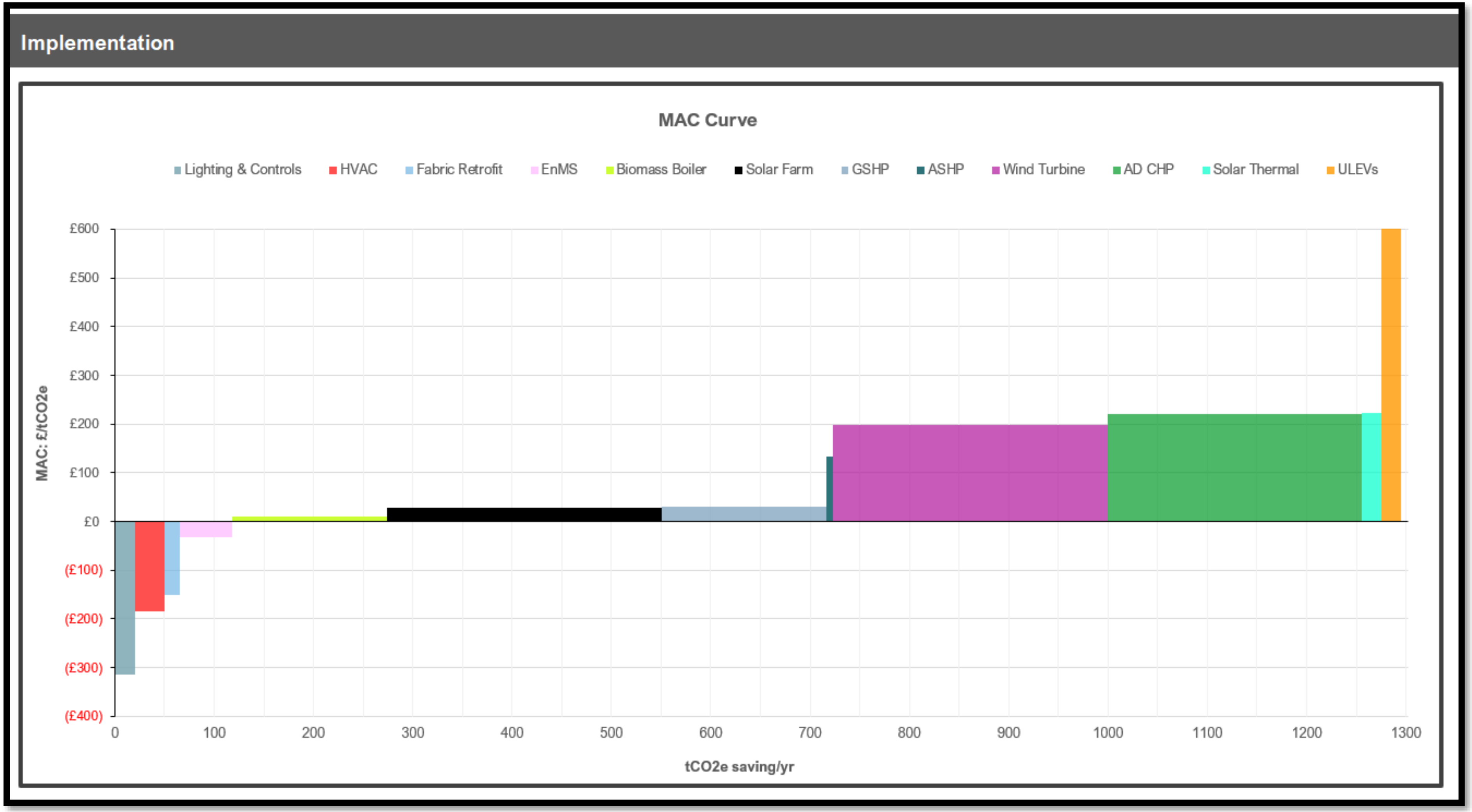
CM-SAM – MACC Analysis



MACC Calculator

Carbon Reduction Measures	MAC	tCO2e	tCO2e	Lighting & Controls	HVAC	Fabric Retrofit	EnMS	Biomass Boiler	Solar Farm	GSHP	ASHP	Wind Turbine	AD CHP	Solar Thermal	ULEVs
Fabric Retrofit	- 314.28	20.42	0												
Energy Management System (EMS)	- 184.46	29.84	0	- 314.28											
Lighting & Controls	- 151.53	15.73	20.42	- 314.28											
Infrared Heating	- 33.56	52.16	20.42		- 184.46										
Biomass Systems	10.23	156.55	50.25		- 184.46										
Solar PV	27.48	277.21	50.25			- 151.53									
Solar Thermal	30.13	164.50	65.98			- 151.53									
Ground Source Heat Pumps (GSHP)	133.83	6.68	65.98				- 33.56								
Air Source Heat Pumps (ASHP)	198.56	277.21	118.14				- 33.56								
Rainwater Harvesting (RH)	220.43	255.59	118.14					10.23							
Ultra-Low Emissions Vehicles (ULEV)	222.90	19.19	274.69					10.23							
	######	20.00	274.69						27.48						
			551.91						27.48						
			551.91							30.13					
			716.41							30.13					
			716.41								133.83				
			723.09								133.83				
			723.09									198.56			
			1,000.30									198.56			
			1,000.30										220.43		
			1,255.89										220.43		
			1,255.89											222.90	
			1,275.08											222.90	
			1,275.08												2,006.40
			1,295.08												2,006.40
			1,295.08												
			1,295.08												
			1,295.08												
			1,295.08												
			1,295.08												
			1,295.08												
			1,295.08												

Appendix Figure 22. CM-SAM -MACC Analysis 01

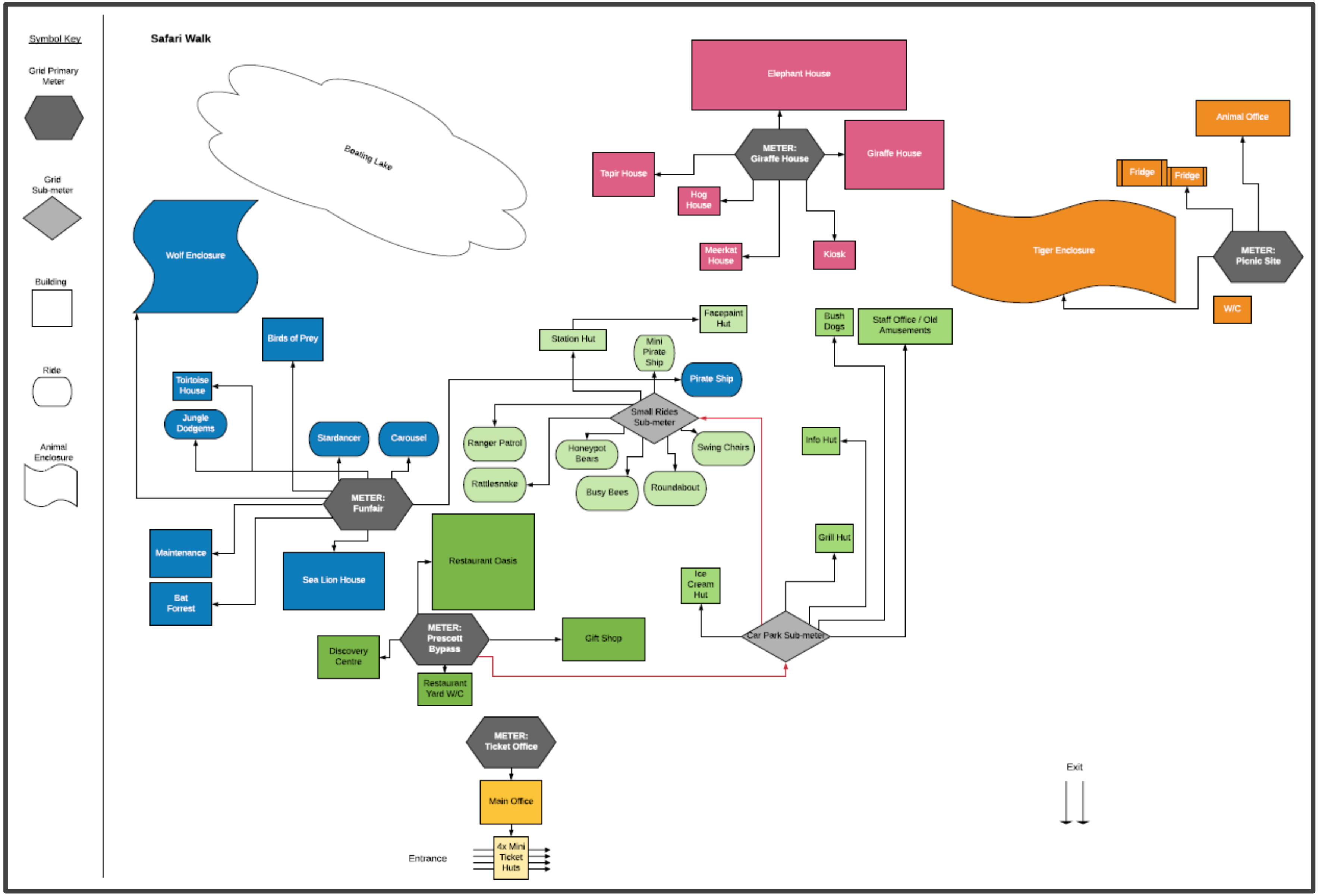


Appendix Figure 23. CM-SAM -MACC Analysis 02

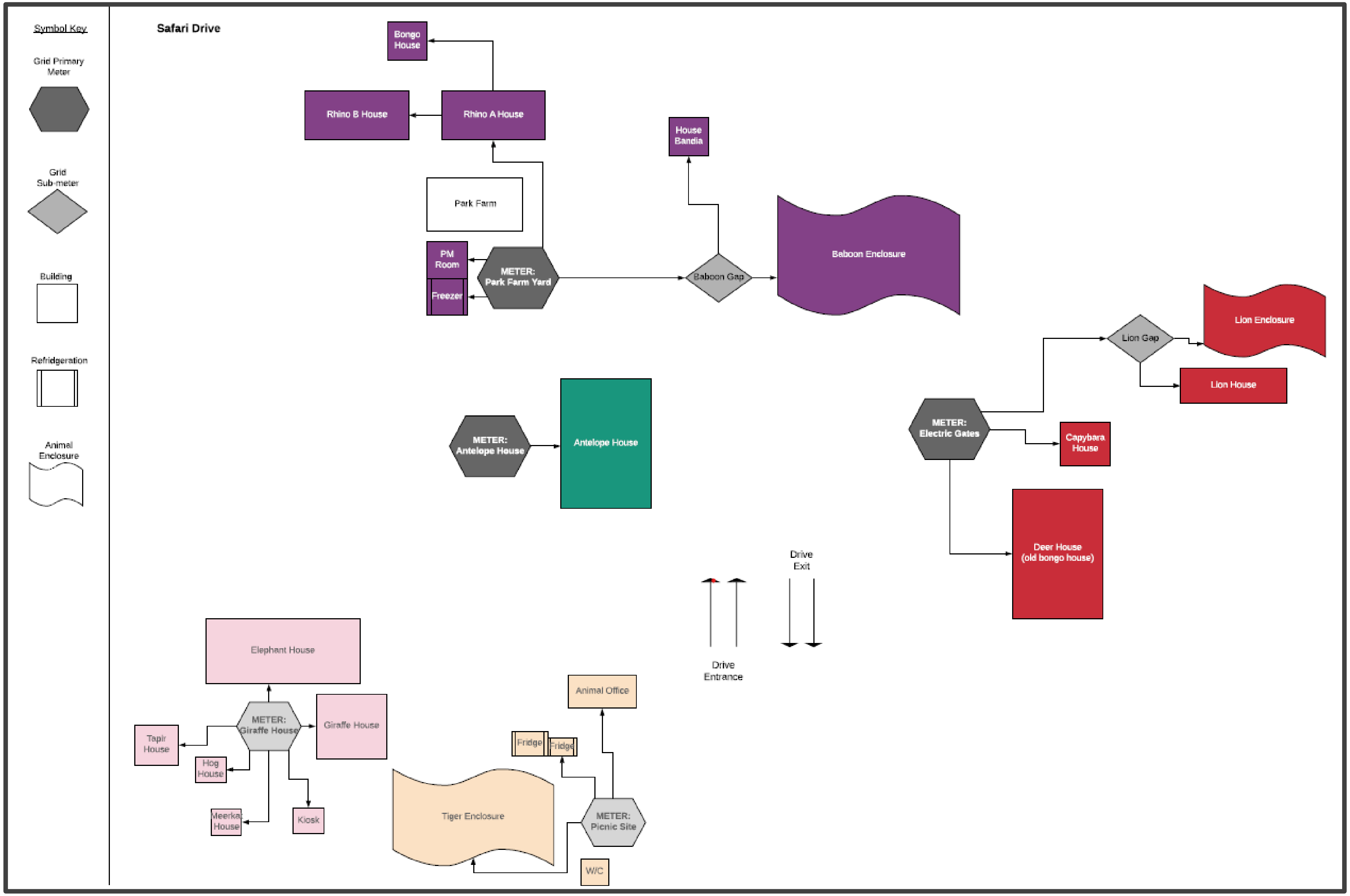
Appendix E – Knowsley Safari Case Study

Appendix E1 – Knowsley Safari Meter Maps

See next page for meter maps



Appendix Figure 24. Knowsley Safari – Electricity Meter Map – Safari Walk



Appendix Figure 25. Knowsley Safari – Electricity Meter Map – Safari Drive

Appendix E2 - Knowsley Safari – Site Survey & Energy Audit

Appendix Table 5. Knowsley Safari Site Audit

Area	Type	Name	Heating	Lights	Sockets	Electric Fences	Electric Gates	Cameras	Fridges	Scope
Safari Drive	**Animal House**	**Rhino House A**	**LPG space heating system**	**Fluorescent Tubes**	**Yes**	**No**	**N/A**	**Yes**	**No**	**1 + 2**
Safari Drive	**Animal House**	**Rhino House B**	**Radiant space heaters**	**Fluorescent Tubes**	**Yes**	**No**	**N/A**		**No**	**2**
Safari Drive	**Animal House**	**Bongo House**	**Radiant space heaters**	**Fluorescent Tubes**	**Yes**	**No**	**N/A**		**No**	**2**
Safari Drive	**Animal House**	**House Bandia**	**NONE**	**LED**	**Yes**	**No**	**N/A**	**No**	**No**	**2**
Safari Drive	**Animal House**	**Lion House**	**NONE**	**Unsure of Fitting**	**Yes**	**Yes**	**N/A**	**Yes**	**No**	**2**
Safari Drive	**Animal House**	**Baboon House**	**NONE**	**Unsure of Fitting**	**Yes**	**No**	**N/A**	**No**	**No**	**2**
Safari Drive	**Animal House**	**Antelope House**	**Underfloor Heating - ASHP + Halogen heaters**	**Unsure of Fitting**	**Yes**	**No**	**No**	**No**	**No**	**2**
Safari Drive	**Animal House**	**Tiger House**								
Safari Drive	**Animal House**	**Capybara House (previously wolf)**	**Halogen heaters**	**Unsure of Fitting**	**Yes**	**Yes**	**Unsure**		**No**	**2**
Safari Drive	**Office**	**Monkey Gap (Staff Hut)**	**Electric Heater**	**Unsure of Fitting**	**Yes**	**No**	**N/A**	**No**	**Yes**	**2**

Safari Drive	Office	Tower (Surveillance)	Electric Heater	Unsure of Fitting	Yes	No	Yes	Yes		2
Safari Drive	Office	Lion Gap (Staff Hut)	Electric Heater	Unsure of Fitting	Yes	No	N/A			2
Safari Drive	Office	Park Farm	Oil Central Heating	Multiple Fittings	Yes	Yes	Unsure		Yes	1 + 2
Safari Drive	Office	Animal Office	Electric Heater	Unsure of Fitting	Yes	No	No	Yes	Yes	2
Safari Drive	Section	Rhino A	N/A	N/A	N/A	Yes	No		No	2
Safari Drive	Section	Rhino B	N/A	N/A	N/A	Yes	No		No	2
Safari Drive	Section	Woods - (bongo house)	N/A	N/A	N/A	Yes	No	No	No	2
Safari Drive	Section	The Loop	N/A	N/A	N/A	Yes	Unsure		No	2
Safari Drive	Section	First Section	N/A	N/A	N/A	Yes	No	No	No	2
Safari Drive	Animal Enclosure	Baboons	N/A	N/A	N/A	Yes	Yes		No	2
Safari Drive	Animal Enclosure	Lions	N/A	N/A	N/A	Yes	Yes		No	2
Safari Drive	Animal Enclosure	Capybara (previously wolf)	N/A	N/A	N/A	Yes	No		No	2
Safari Drive	Animal Enclosure	Tigers	N/A	N/A	N/A	Yes	Unsure		No	2
Foot Safari	Animal House	Elephant House	NONE	Unsure of Fitting	Yes		No	Yes	No	2
Foot Safari	Animal House	Giraffe House	LPG warm air heater - HVAC system	LED	Yes		No		No	1 + 2

Foot Safari	Animal House	Hog House	Halogen heaters + Heat lamp	Standard Screw or Bayonet	Yes	Yes	No		No	2
Foot Safari	Animal House	Tapir House	Radiant space heaters	Unsure of Fitting	Yes	Yes	No		No	2
Foot Safari	Animal House	Meerkat House	Electric Heater + Heat lamp	Standard Screw or Bayonet	Yes		No		No	2
Foot Safari	Animal House	Bush Dog House	Radiant space heaters	Unsure of Fitting	Yes	Yes	No		No	2
Foot Safari	Animal House	Sea Lion House								
Foot Safari	Animal House	Bat Forest	Radiant space heaters	Unsure of Fitting	Yes	No	No	No	No	2
Foot Safari	Animal House	Bird of Prey House	NONE							
Foot Safari	Animal House	Wolf House	NONE							
Foot Safari	Animal Enclosure	Wolf Enclosure	N/A							
Foot Safari	Office	Elephant Office	Electric Heater	Unsure of Fitting	Yes	No	No			2
Foot Safari	Office	Ride Ticket Office	Electric Heater	Unsure of Fitting	Yes	No	No	Yes	Yes	2
Foot Safari	Office	Maintenance	Electric Heater	Multiple Fittings	Yes	No	No			2
Foot Safari	Office	Ticket Office	LPG Central Heating							

Foot Safari	Ride	Pirate Ship	N/A	N/A	N/A	No	No	N/A	N/A	2
Foot Safari	Ride	Swing Chairs	N/A	N/A	N/A	No	No	N/A	N/A	2
Foot Safari	Ride	Busy Bees	N/A	N/A	N/A	No	No	N/A	N/A	2
Foot Safari	Ride	Roundabout	N/A	N/A	N/A	No	No	N/A	N/A	2
Foot Safari	Ride	Honypot Bear	N/A	N/A	N/A	No	No	N/A	N/A	2
Foot Safari	Ride	Mini Pirate Ship	N/A	N/A	N/A	No	No	N/A	N/A	2
Foot Safari	Ride	Ranger Patrol	N/A	N/A	N/A	No	No	N/A	N/A	2
Foot Safari	Ride	Rattlesnake	N/A	N/A	N/A	No	No	N/A	N/A	2
Foot Safari	Ride	Carousel	N/A	N/A	N/A	No	No	N/A	N/A	2
Foot Safari	Ride	Stardancer	N/A	N/A	N/A	No	No	N/A	N/A	2
Foot Safari	Ride	Jungle Dodgems	N/A	N/A	N/A	No	No	N/A	N/A	2
Foot Safari	Restaurant	Oasis (Main)	LPG space heating system	Multiple Fittings	Yes	No	No	Yes	Yes	1 + 2
Foot Safari	Restaurant	Ice Cream Hut	NONE	Unsure of Fitting	Yes	No	No			2
Foot Safari	Restaurant	Grill Hut	NONE	Unsure of Fitting	Yes	No	No			1 + 2
Foot Safari	Restaurant	Snack Hut	NONE							
Foot Safari	Other	Face Paint Hut	NONE							
Foot Safari	Other	Discovery Centre/ Reptile House	Electric Heater + Heat lamp							
Foot Safari	Other	W.C. (near restaurant)	NONE							

Foot Safari	**Other**	**Gift Shop**	**AC Unit**							
Foot Safari	**Other**	**Party Rooms**	**Electric Heater**							
Transport	**Owned Transport**	**Trucks**	**N/A**							**1**
Transport	**Owned Transport**	**Cars**	**N/A**							**1**
Transport	**Owned Transport**	**Baboon Bus**	**N/A**							**1**

Appendix Table 6. Knowsley Safari Visitor Numbers

	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
*JANUARY	**9,054**	**9,657**	**14,245**	**13,332**	**12,634**	**14,919**	**17,723**	**10,991**	**12,351**	**8,975**	**6,887**	**12,069**	**8,329**	**23,073**	**26,199**	**49,904**	**41,302**
FEBRUARY	**28,485**	**35,292**	**28,513**	**33,833**	**28,751**	**36,267**	**34,211**	**29,298**	**30,721**	**32,906**	**40,159**	**40,744**	**51,527**	**58,452**	**38,976**	**50,342**	**62,169**
MARCH	**30,059**	**21,574**	**58,638**	**17,857**	**27,133**	**58,632**	**34,998**	**28,528**	**25,526**	**28,774**	**31,091**	**36,223**	**28,539**	**61,331**	**39,776**	**36,567**	**45,443**
APRIL	**68,070**	**74,803**	**40,916**	**87,244**	**82,700**	**42,890**	**84,370**	**65,906**	**58,499**	**54,414**	**56,037**	**81,334**	**66,843**	**58,034**	**67,920**	**56,617**	**70,791**
MAY	**61,257**	**51,983**	**59,632**	**54,378**	**55,989**	**69,510**	**65,651**	**52,204**	**38,677**	**41,698**	**51,047**	**64,421**	**58,399**	**50,436**	**46,382**	**51,046**	**49,161**
JUNE	**39,506**	**44,344**	**47,895**	**49,140**	**45,336**	**45,184**	**44,235**	**44,573**	**40,676**	**55,099**	**41,050**	**42,288**	**81,804**	**68,819**	**53,336**	**47,696**	**47,413**
JULY	**55,247**	**59,332**	**58,341**	**60,226**	**60,393**	**62,427**	**61,798**	**55,231**	**55,417**	**54,889**	**44,266**	**52,643**	**54,260**	**59,196**	**54,952**	**53,496**	**53,714**
AUGUST	**99,466**	**97,751**	**114,919**	**106,619**	**110,667**	**109,211**	**105,705**	**85,418**	**76,594**	**85,440**	**96,528**	**97,180**	**97,766**	**94,245**	**100,523**	**94,282**	**101,253**
SEPTEMBER	**24,999**	**28,801**	**33,011**	**32,263**	**41,092**	**30,995**	**31,979**	**28,784**	**29,836**	**33,326**	**34,435**	**28,039**	**43,418**	**47,702**	**42,463**	**33,737**	
OCTOBER	**24,365**	**27,349**	**30,755**	**34,665**	**35,060**	**30,931**	**34,091**	**31,967**	**34,650**	**26,100**	**32,205**	**34,282**	**50,357**	**53,679**	**38,129**	**32,444**	
NOVEMBER	**8,737**	**8,241**	**9,760**	**12,933**	**13,079**	**13,551**	**11,141**	**10,309**	**6,883**	**12,038**	**12,203**	**10,961**	**8,140**	**15,866**	**23,631**	**24,301**	
DECEMBER	**3,726**	**4,686**	**8,612**	**10,516**	**10,261**	**8,181**	**4,788**	**5,218**	**1,902**	**7,352**	**7,803**	**4,954**	**16,966**	**16,647**	**24,822**	**44,439**	
TOTAL (TO AGREE)	**452,971**	**463,813**	**505,237**	**513,006**	**523,095**	**522,698**	**530,690**	**448,427**	**411,732**	**441,011**	**453,711**	**505,138**	**566,348**	**607,480**	**557,109**	**574,871**	**471,246**

Appendix E3 - Knowsley Safari - Energy & Weather Data

Appendix Table 7. Knowsley Safari Electricity Data

Energy Usage [kWh]										SOLAR					
Date	Ticket Office	Electric Gates	Funfair	Antelope	Picnic Site	Giraffe House	Park Farm Yard	Prescott Bypass	SUM	Sealion	Bat	Education Centre Solar	Antelope 2	Sum2	Avg Temp degrees C
Jan-17	2,469	2,372	31,614	2,939	5,685	11,380	8,618	20,380	85,457	646	163	145	51	1,004	5
Feb-17	2,807	2,129	22,564	3,072	5,079	11,380	9,324	22,826	79,181	1,057	271	238	98	1,664	6
Mar-17	2,539	2,190	23,285	3,072	5,007	11,380	7,853	24,101	79,427	2,693	679	623	267	4,263	9
Apr-17	3,009	2,056	22,336	1,131	4,308	11,380	6,813	26,502	77,535	4,187	1,035	959	433	6,614	9
May-17	2,412	572	12,692	1,131	3,481	11,380	5,965	23,105	60,738	5,385	1,288	1,202	567	8,441	14
Jun-17	1,951	453	17,289	38	3,290	11,380	5,035	21,537	60,973	4,458	1,077	1,007	478	7,019	16
Jul-17	1,754	551	17,289	249	3,127	11,380	3,163	22,365	59,878	5,039	49	1,143	534	6,765	17
Aug-17	2,253	529	16,803	249	3,158	2,897	4,754	26,341	56,984	4,179	0	969	454	5,602	17
Sep-17	2,217	640	680	303	3,270	373	5,620	20,583	33,686	2,678	0	597	271	3,547	14
Oct-17	2,656	1,114	23,151	1,419	3,757	11,060	8,707	23,737	75,601	1,554	0	34	150	1,738	13
Nov-17	2,546	3,259	22,723	2,515	4,587	11,060	11,233	19,813	77,736	1,098	0	234	97	1,429	9
Dec-17	2,449	4,794	27,626	2,571	5,501	11,060	11,233	21,732	86,966	561	0	115	46	722	6
Jan-18	2,673	5,227	29,447	3,087	6,086	12,356	14,216	22,235	95,327	792	0	84	69	945	6

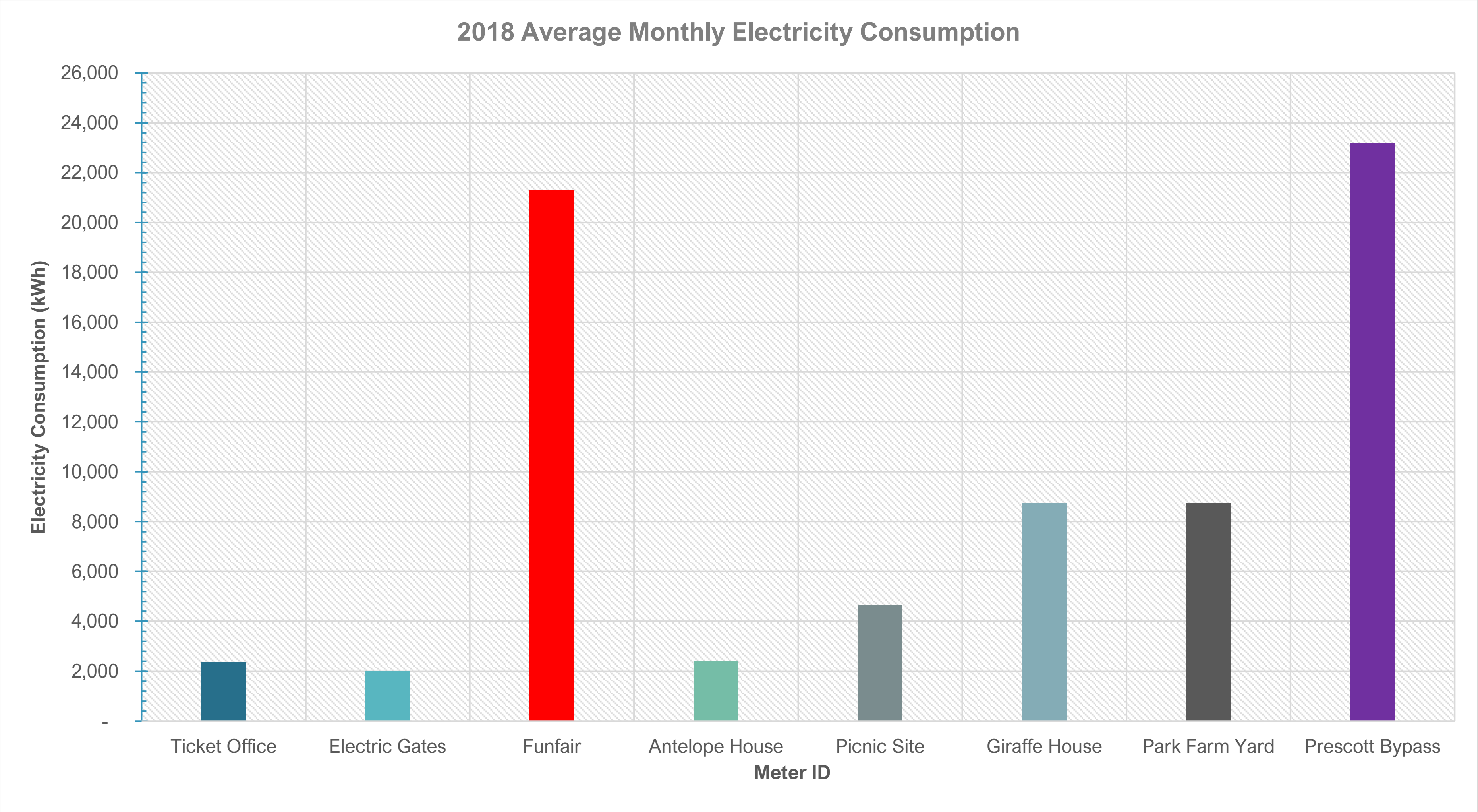
Feb-18	**2,945**	**4,811**	**29,447**	**15,002**	**6,442**	**12,678**	**16,013**	**24,563**	**111,901**	**1,620**	**0**	**0**	**149**	**1,768**	**4**
Mar-18	**2,644**	**5,143**	**28,628**	**5,457**	**7,122**	**12,057**	**17,543**	**25,333**	**103,927**	**2,470**	**0**	**0**	**244**	**2,714**	**6**
Apr-18	**2,594**	**3,496**	**25,522**	**3,256**	**5,438**	**9,302**	**10,792**	**25,074**	**85,474**	**3,307**	**0**	**0**	**344**	**3,651**	**10**
May-18	**1,713**	**704**	**15,945**	**502**	**4,345**	**2,657**	**4,612**	**21,990**	**52,468**	**6,107**	**0**	**0**	**638**	**6,744**	**15**
Jun-18	**1,571**	**463**	**14,594**	**155**	**3,834**	**1,787**	**2,941**	**20,849**	**46,194**	**6,035**	**0**	**0**	**647**	**6,681**	**19**
Jul-18	**1,614**	**442**	**14,217**	**245**	**4,005**	**1,845**	**2,997**	**23,116**	**48,481**	**5,635**	**0**	**0**	**589**	**6,224**	**21**
Aug-18	**2,008**	**656**	**19,201**	**516**	**4,088**	**2,193**	**3,736**	**26,676**	**59,074**	**3,641**	**0**	**0**	**386**	**4,027**	**18**
Sep-18	**2,050**	**146**	**756**	**414**	**3,656**	**6,116**	**7,798**	**20,408**	**41,344**	**2,853**	**0**	**0**	**296**	**3,149**	**15**
Oct-18	**2,516**	**1,435**	**26,403**	**1,342**	**3,753**	**9,615**	**14,447**	**23,899**	**83,410**	**1,818**	**0**	**0**	**176**	**1,994**	**12**
Nov-18	**2,804**	**2,249**	**27,110**	**4,172**	**4,529**	**10,543**	**17,132**	**24,065**	**92,604**	**917**	**0**	**123**	**83**	**1,123**	**9**
Dec-18	**3,000**	**2,434**	**30,219**	**4,553**	**5,450**	**12,261**	**16,519**	**28,403**	**102,839**	**554**	**0**	**118**	**46**	**718**	**8**
	57,194	**47,865**	**499,541**	**57,390**	**108,998**	**209,520**	**217,064**	**559,633**	**1,757,205**	**69,284**	**4,561**	**7,591**	**7,110**	**88,547**	

Appendix Table 8. Knowsley Safari LPG Data

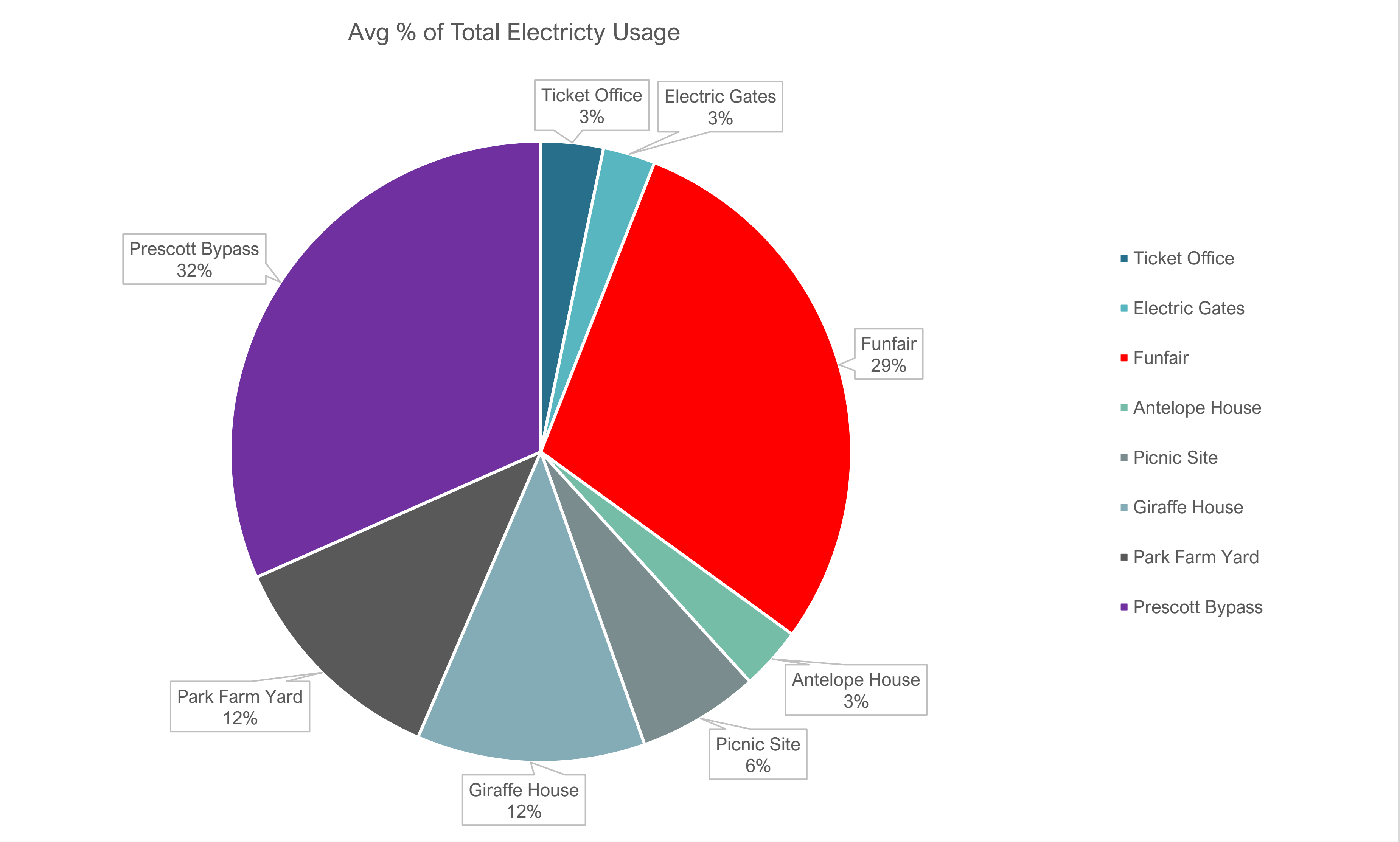
Date	Cafeteria	Rhino House	Giraffe House	Office Block	Total Litres Delivered	Energy [kWh]
Jan-15	3,704	2,940	10,615	1,444	18,703	132,417
Feb-15		2,199	9,316		11,515	81,526
Mar-15	4,796	2,756	9,995	1,412	18,959	134,230
Apr-15		1,141	7,937		9,078	64,272
May-15	5,437	1,259	4,041		10,737	76,018
Jun-15					0	0
Jul-15	4,556			1,409	5,965	42,232
Aug-15					0	0
Sep-15					0	0
Oct-15	4,862		8,307		13,169	93,237
Nov-15	3,661	1,985	9,520	1,115	16,281	115,269
Dec-15	2,669	3,106	9,386	969	16,130	114,200
Jan-16	2,342	4,526	11,752	942	19,562	138,499
Feb-16		3,607	10,515		14,122	99,984
Mar-16	4,449	4,132	14,886	1,661	25,128	177,906
Apr-16	4,887	944	4,462		10,293	72,874
May-16		1,694	5,392		7,086	50,169
Jun-16	4,925				4,925	34,869
Jul-16	2,750			1,114	3,864	27,357
Aug-16					0	0
Sep-16					0	0
Oct-16	4,704		4,816		9,520	67,402
Nov-16	2,867	2,895	19,101	1,240	26,103	184,809
Dec-16	4,046	2,577	8,852		15,475	109,563
Jan-17	0	3,516	16,426	1,797	21,739	153,912

Feb-17	**4,000**	**3,374**	**9,851**	**0**	**17,225**	**121,953**
Mar-17	**4,782**	**2,635**	**11,328**	**1,791**	**20,536**	**145,395**
Apr-17	**3,340**	**1,035**	**4,632**	**0**	**9,007**	**63,770**
May-17	**3,193**	**1,980**	**9,337**	**1,073**	**15,583**	**110,328**
Jun-17	**0**	**0**	**0**	**0**	**0**	**0**
Jul-17	**3,827**	**0**	**3,871**	**0**	**7,698**	**54,502**
Aug-17	**0**	**0**	**0**	**0**	**0**	**0**
Sep-17	**4,555**	**0**	**7,430**	**0**	**11,985**	**84,854**
Oct-17	**1,974**	**0**	**6,661**	**822**	**9,457**	**66,956**
Nov-17	**0**	**2,493**	**1,687**	**2,772**	**6,952**	**49,220**
Dec-17	**0**	**6,001**	**4,633**	**1,228**	**11,862**	**83,983**
Jan-18	**4,655**	**3,293**	**2,053**	**1,634**	**11,635**	**82,376**
Feb-18	**4,548**	**4,729**	**5,355**	**0**	**14,632**	**103,595**
Mar-18	**4,067**	**6,493**	**3,156**	**1,641**	**15,357**	**108,728**
Apr-18	**4,753**	**1,723**	**0**	**1,491**	**7,967**	**56,406**
May-18	**0**	**0**	**2,970**	**0**	**2,970**	**21,028**
Jun-18	**3,818**	**0**	**0**	**0**	**3,818**	**27,031**
Jul-18	**0**	**0**	**0**	**0**	**0**	**0**
Aug-18	**5,055**	**0**	**0**	**0**	**5,055**	**35,789**
Sep-18	**0**	**0**	**0**	**0**	**0**	**0**
Oct-18	**0**	**0**	**0**	**0**	**0**	**0**
Nov-18	**4,297**	**901**	**6,133**	**1,462**	**12,793**	**90,574**
Dec-18	**3,941**	**0**	**10,760**	**1,349**	**16,050**	**113,634**
Jan-19	**3,243**	**6,030**	**19,912**	**1,106**	**30,291**	**214,460**
Feb-19	**7,590**	**2,842**	**10,753**	**1,102**	**22,287**	**157,792**
Mar-19	**3,547**	**3,892**	**14,378**	**1,014**	**22,831**	**161,643**
Apr-19	**4,311**	**2,641**	**2,963**		**9,915**	**70,198**
May-19		**3,540**			**1,770**	**12,532**
Jun-19					**1,770**	**12,532**

Jul-19	**4,963**		**3,112**	**1,159**	**9,234**	**65,377**
	145,114	**92,879**	**306,294**	**32,747**	**577,034**	



Appendix Figure 26. Knowsley Safari Electricity Meter Data 01



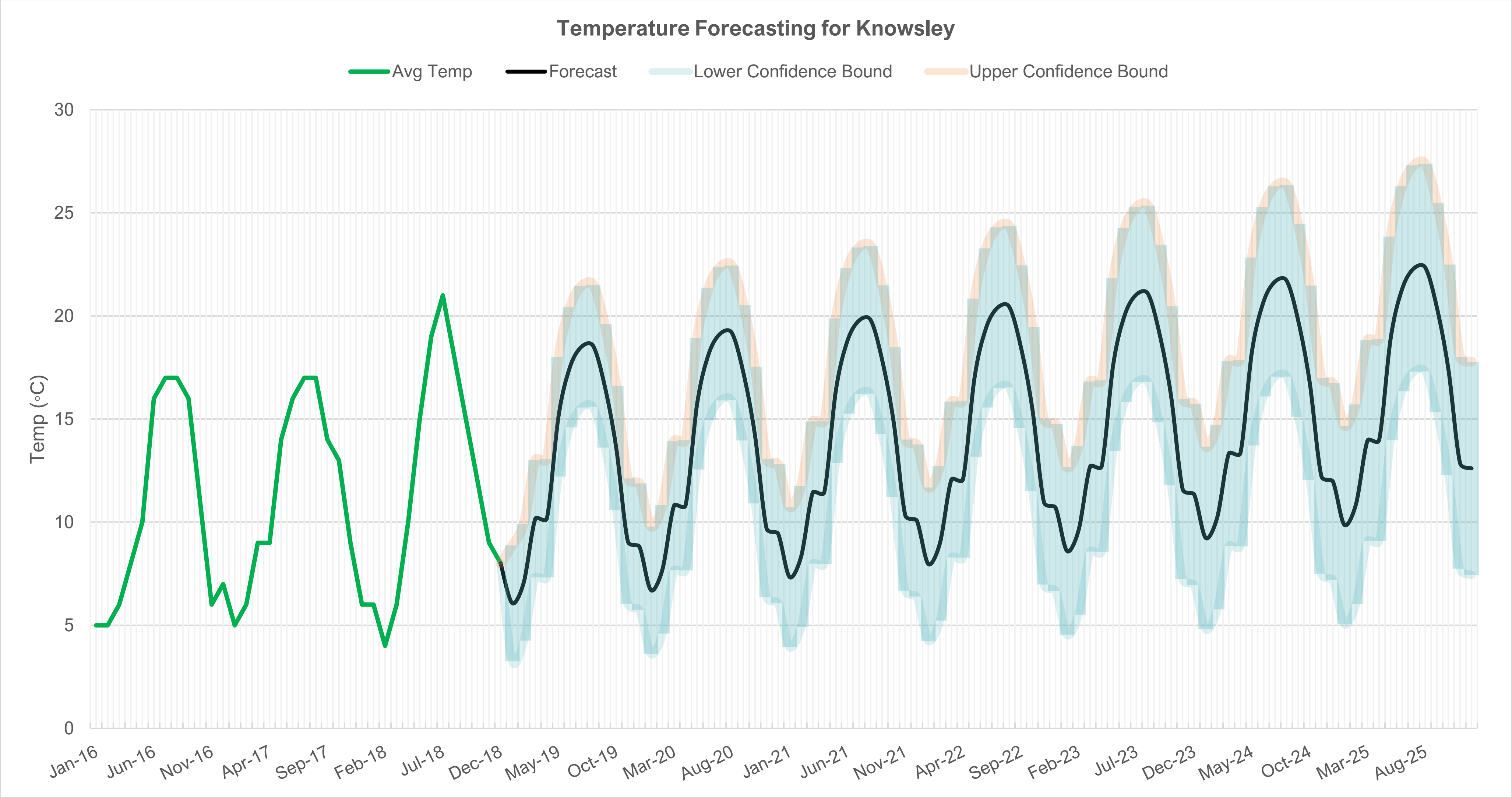
Appendix Figure 27. Knowsley Safari Electricity Meter Data 02

Appendix Table 9. Knowsley Weather Data

Date		Temperature				Precipitation			Wind			Pressure	Cloud & Humidity		UV Index	Sun	
Date	**Month**	**Year**	**Max (°C)**	**Min (°C)**	**Average (°C)**	**Rainfall (mm)**	**Rain Days**	**Snowfall (cm)**	**Snow Days**	**Max Wind (kmph)**	**Avg Wind (kmph)**	**Avg Gust (kmph)**	**Pressure (mb)**	**Cloud (%)**	**Humidity (%)**	**UV Index**	**Sun Hours (hrs)**
Jan-16	Jan	2016	7	4	5	148.4	28	0.3	1	28.8	21.1	39.8	1004.8	74	85	2	74
Feb-16	Feb	2016	8	3	5	123	22	0	0	28.5	20.9	36.7	1007.6	63	79	1	103.5
Mar-16	Mar	2016	9	3	6	93.9	17	1.6	1	23.1	16	27.2	1013.9	59	81	2	145.5
Apr-16	Apr	2016	12	5	8	108.2	23	4.6	1	26.6	18	28.2	1011.7	58	76	2	202.5
May-16	May	2016	17	13	10	79.9	25	0	0	22	16.5	24.7	1014.5	56	81	4	197.5
Jun-16	Jun	2016	19	13	16	132.4	25	0	0	18	12.6	17.4	1013.2	70	86	4	132.5
Jul-16	Jul	2016	19	14	17	134.4	29	0	0	20.3	14.3	22.3	1015.2	65	86	4	175
Aug-16	Aug	2016	20	14	17	96.6	23	0	0	20.7	15.6	23.8	1016.6	64	83	4	187
Sep-16	Sep	2016	19	13	16	83.6	24	0	0	19.5	14.2	24.1	1014.7	61	84	3	162.5
Oct-16	Oct	2016	14	8	11	26.3	18	0	0	17.9	13	22.5	1021.9	55	85	4	121
Nov-16	Nov	2016	9	4	6	124.3	22	0	0	21.4	14.6	24.3	1014.8	56	86	4	115
Dec-16	Dec	2016	9	5	7	57.8	21	0	0	20.1	15.7	26.8	1024.8	67	91	2	84

Jan-17	**Jan**	**2017**	**8**	**3**	**5**	**90.7**	**20**	**6**	**3**	**23**	**17.1**	**28**	**1021.9**	**70**	**89**	**2**	**90.5**
Feb-17	**Feb**	**2017**	**9**	**4**	**6**	**93.8**	**24**	**1.6**	**3**	**28.2**	**19.5**	**30.6**	**1011.5**	**77**	**88**	**1**	**60**
Mar-17	**Mar**	**2017**	**12**	**5**	**9**	**123.4**	**24**	**0**	**0**	**25.4**	**18**	**28.2**	**1012.8**	**64**	**86**	**3**	**138**
Apr-17	**Apr**	**2017**	**13**	**6**	**9**	**38.7**	**21**	**0.3**	**1**	**23.5**	**16.7**	**24.8**	**1022.2**	**61**	**82**	**3**	**182**
May-17	**May**	**2017**	**18**	**10**	**14**	**76**	**23**	**0**	**0**	**19.6**	**14.4**	**21.4**	**1016.1**	**52**	**82**	**4**	**203**
Jun-17	**Jun**	**2017**	**19**	**13**	**16**	**170.7**	**27**	**0**	**0**	**23**	**16.4**	**24.3**	**1011.4**	**69**	**86**	**4**	**138**
Jul-17	**Jul**	**2017**	**21**	**14**	**17**	**117**	**26**	**0**	**0**	**19**	**14.1**	**19.9**	**1012.7**	**64**	**79**	**4**	**180**
Aug-17	**Aug**	**2017**	**21**	**14**	**17**	**97.5**	**26**	**0**	**0**	**17.2**	**12.9**	**17.6**	**1014.6**	**56**	**73**	**4**	**198**
Sep-17	**Sep**	**2017**	**17**	**12**	**14**	**191.1**	**25**	**0**	**0**	**19.5**	**14.5**	**21.2**	**1011.4**	**63**	**78**	**3**	**159.5**
Oct-17	**Oct**	**2017**	**15**	**12**	**13**	**129.1**	**19**	**0**	**0**	**22.4**	**16.7**	**24.9**	**1015.1**	**74**	**78**	**3**	**68**
Nov-17	**Nov**	**2017**	**10**	**8**	**9**	**180.8**	**28**	**0**	**0**	**19.5**	**14.6**	**22.2**	**1014.9**	**73**	**73**	**2**	**94.5**
Dec-17	**Dec**	**2017**	**8**	**5**	**6**	**164.1**	**25**	**26.8**	**4**	**19.3**	**14**	**22.4**	**1012**	**71**	**80**	**2**	**80**
Jan-18	**Jan**	**2018**	**7**	**5**	**6**	**212.7**	**27**	**2.1**	**2**	**24.7**	**18.2**	**28.5**	**1008.1**	**73**	**78**	**2**	**79**
Feb-18	**Feb**	**2018**	**6**	**3**	**4**	**94.3**	**17**	**20.7**	**9**	**21.4**	**15.3**	**23.2**	**1017**	**59**	**73**	**1**	**96**
Mar-18	**Mar**	**2018**	**8**	**3**	**6**	**150.1**	**21**	**2.5**	**3**	**22.2**	**16.2**	**23**	**1002.2**	**76**	**76**	**2**	**86.5**
Apr-18	**Apr**	**2018**	**14**	**8**	**10**	**145.4**	**25**	**0**	**0**	**19.4**	**14**	**21.1**	**1009.4**	**69**	**75**	**2**	**136**
May-18	**May**	**2018**	**19**	**11**	**15**	**70.4**	**17**	**0**	**0**	**15.9**	**11.4**	**15.4**	**1018.2**	**46**	**68**	**4**	**258.5**
Jun-18	**Jun**	**2018**	**22**	**15**	**19**	**18.4**	**15**	**0**	**0**	**14.8**	**10.9**	**14.4**	**1019.6**	**43**	**65**	**6**	**247.5**
Jul-18	**Jul**	**2018**	**23**	**17**	**21**	**54.4**	**17**	**0**	**0**	**12.4**	**8.7**	**11.2**	**1018.3**	**41**	**65**	**5**	**263.5**

Aug-18	**Aug**	**2018**	**20**	**15**	**18**	**109.4**	**26**	**0**	**0**	**17.3**	**12.7**	**18**	**1014.3**	**64**	**72**	**5**	**168.5**
Sep-18	**Sep**	**2018**	**17**	**12**	**15**	**121.4**	**28**	**0**	**0**	**19.4**	**14**	**19.9**	**1019.3**	**68**	**73**	**3**	**126**
Oct-18	**Oct**	**2018**	**14**	**10**	**12**	**92.5**	**22**	**0**	**0**	**19**	**14.5**	**21.3**	**1017.6**	**61**	**76**	**2**	**90.5**
Nov-18	**Nov**	**2018**	**11**	**8**	**9**	**99.5**	**25**	**0**	**0**	**21.9**	**16.9**	**24.7**	**1009.9**	**70**	**80**	**2**	**80.5**
Dec-18	**Dec**	**2018**	**9**	**6**	**8**	**219.4**	**26**	**0**	**0**	**21**	**15**	**23.3**	**1013.9**	**81**	**84**	**2**	**63**
Jan-19	**Jan**	**2019**	**7**	**4**	**6**	**104.7**	**24**	**15.7**	**4**	**19.6**	**13.9**	**21.2**	**1017.4**	**70**	**79**	**1**	
Feb-19	**Feb**	**2019**	**11**	**6**	**8**	**60.3**	**16**	**0**	**0**	**19.8**	**14.8**	**22.9**	**1016.7**	**52**	**77**	**2**	
Mar-19	**Mar**	**2019**	**11**	**6**	**9**	**226.2**	**25**	**0**	**0**	**23.8**	**17.5**	**25.4**	**1013.6**	**74**	**73**	**2**	
Apr-19	**Apr**	**2019**	**15**	**5**	**10**	**97.8**	**16**	**0**	**0**	**19.5**	**14.8**	**20.4**	**1014.2**	**49**	**67**	**3**	
May-19	**May**	**2019**	**15**	**9**	**13**												
Jun-19	**Jun**	**2019**	**18**	**11**	**16**												
Jul-19	**Jul**	**2019**	**21**	**15**	**19**												
Aug-19	**Aug**	**2019**	**21**	**15**	**19**												



Appendix Figure 28. Knowsley Average Temps Forecasting Analysis

Appendix Table 10. Knowsley Safari Vehicle Data

Vehicle	Vehicle Type	CC	Fuel	Car Size	Estimated 2018 Mileage
Mitsubishi Shogun DI-D Equippe	**Commercial Vehicle**	**3200**	**Diesel**	**Large**	**13327**
Mitsubishi Shogun Elegance	**Commercial Vehicle**	**3200**	**Diesel**	**Large**	**20000**
Nissan Navara	**Commercial Vehicle**	**2488**	**Diesel**	**Large**	**6712**
Toyota Hi Lux	**Commercial Vehicle**	**2494**	**Diesel**	**Large**	**6000**
Land Rover 90 Defender	**Commercial Vehicle**	**2495**	**Diesel**	**Large**	**3037**
Land Rover 110 Defender	**Commercial Vehicle**	**2495**	**Diesel**	**Large**	**1479**
Toyota Hi Lux	**Commercial Vehicle**	**2494**	**Diesel**	**Large**	**6000**
Goupil G5 Hybrid Truck	**Plant Equipment**	**500**	**Diesel**	**Large**	**6000**
Ford Transit Tipper	**Commercial Vehicle**	**2402**	**Diesel**	**Large**	**5000**
Ford Ranger 4x4 Pick Up	**Commercial Vehicle**	**2500**	**Diesel**	**Large**	**5000**
Ford Ranger Supercab Pick Up	**Commercial Vehicle**	**2500**	**Diesel**	**Large**	**6000**
Ford Ranger 4x4 Pick up (Silver)	**Commercial Vehicle**	**2500**	**Diesel**	**Large**	**6000**
Ford Ranger 4x4 Pick up	**Commercial Vehicle**	**2499**	**Diesel**	**Large**	**8000**
Ford Ranger 4x4 Pick up	**Commercial Vehicle**	**2499**	**Diesel**	**Large**	**6000**
Ford Ranger 4x4 Pick up	**Commercial Vehicle**	**2499**	**Diesel**	**Large**	**6000**
Ford Transit 100 T350EF Dropside	**Commercial Vehicle**	**2402**	**Diesel**	**Large**	**18115**

Toyota Hi Lux D/Cab Pick up	**Commercial Vehicle**	**2494**	**Diesel**	**Large**	**12000**
Toyota Hi Lux Pick Up	**Commercial Vehicle**	**2494**	**Diesel**	**Large**	**8000**
Large bus	**Passenger Vehicle**	**4461**	**Diesel**	**Large**	**3000**
Minibus	**Passenger Vehicle**	**2402**	**Diesel**	**Large**	**3729**
Minibus	**Passenger Vehicle**	**2402**	**Diesel**	**Large**	**1920**
Minibus	**Passenger Vehicle**	**2402**	**Diesel**	**Large**	**2000**
Discovery	**Commercial Vehicle**	**2993**	**Diesel**	**Large**	**8000**
Mitsubishi L200	**Commercial Vehicle**	**2477**	**Diesel**	**Large**	**5000**
Mitsubishi L200	**Commercial Vehicle**	**2477**	**Diesel**	**Large**	**2000**
Mitsubishi L200 Warrior	**Commercial Vehicle**	**2477**	**Diesel**	**Large**	**6000**
Mitsubishi L200	**Commercial Vehicle**	**2477**	**Diesel**	**Large**	**6000**
John Deere Tractor 2140	**Plant Equipment**		**Diesel**	**Large**	**1000**
Massey Ferguson Tractor	**Plant Equipment**		**Diesel**	**Large**	**1000**
Ford 5030 Tractor	**Plant Equipment**		**Diesel**	**Large**	**1000**
Kubota M5091 Tractor	**Plant Equipment**	**3769**	**Diesel**	**Large**	**1000**
Ford Focus CL Diesel	**Passenger Vehicle**	**1753**	**Diesel**	**Medium**	**7312**
Ford Focus Eco Estate	**Passenger Vehicle**	**1560**	**Diesel**	**Medium**	**6000**
Caddy Van	**Commercial Vehicle**		**Diesel**	**Medium**	**6000**

Vauxhall Corsa Van	**Commercial Vehicle**	**1248**	**Diesel**	**Small**	**2727**
Vauxhall Combo Van	**Commercial Vehicle**	**1248**	**Diesel**	**Small**	**4000**
Combo Van	**Commercial Vehicle**	**1248**	**Diesel**	**Small**	**6000**
Combo Van	**Commercial Vehicle**	**1248**	**Diesel**	**Small**	**6000**
Kubota Tractor	**Plant Equipment**		**Diesel**	**Small**	**1000**
John Deere Gator	**Plant Equipment**		**Diesel**	**Small**	**1000**
Peugeot 208	**Passenger Vehicle**	**1000**	**Petrol**	**Small**	**2000**
Subaru	**Passenger Vehicle**	**650**	**Petrol**	**Small**	**6000**
42					**232357**

Knowsley Safari

Low Carbon Energy Audit

Appendix E4 - Energy Conservation Measures (ECMs) & Assumptions

Fabric Efficiency

Proposed Measures

a) Insulation upgrade
b) Draught Proofing
c) General Building Maintenance

Assumptions

Based on observations, it is estimated that 12 buildings may require fabric retrofits whether it be the installation of new insulation, draught proofing on leaky buildings, or general building maintenance to improve the thermal efficiency of the buildings whilst retaining full functionality. Buildings recommended are listed as follows:

Fabric Efficiency Audit

Building Reference	Building Size	Recommended Insulation	Draught Proofing Required	General Building Maintenance
Rhino House A	Large	Walls & Roof	Yes	n/a
Rhino House B	Large	Walls & Roof	Audit Required	n/a
Bongo House	Small	Roof	Audit Required	n/a
Lion House	Medium	Audit Required	n/a	Audit Required
Animal Office	Medium	Walls & Roof	Yes	Audit Required
Giraffe House	Extra Large	Walls & Roof	Yes!	Yes
Hog House	Small	Roof	Audit Required	n/a
Tapir House	Small	Roof	Audit Required	n/a
Sea Lion House	Extra Large	Roof	n/a	n/a
Oasis Restaurant	Large	Roof	Yes	Audit Required
Discovery Centre	Medium	Roof	n/a	n/a

Gift Shop	Medium	Roof	Audit Required	n/a

An estimated average cost was taken for each of the fabric retrofit measures. Multiple sources were collated and an average figure was taken for each measure, the values will vary hugely depending on supplier, building requirements, and level of thermal efficiency required. In addition to this, energy savings from the implementation of these measures were estimated based a number of sources.

Fabric Efficiency Measure Costs (Estimates)

Building Size	Wall Insulation	Roof Insulation	Draught Proofing	Building Maintenance
Small	£170	£100	£70	£250
Medium	£250	£150	£105	£500
Large	£500	£300	£210	£750
Extra Large	£750	£450	£315	£1000

Estimated Fabric Efficiency Measure Annual Savings [£/year]

Building Size	Wall Insulation	Roof Insulation	Draught Proofing	Building Maintenance
Small	£47	£60	£20	£70
Medium	£70	£90	£30	£105
Large	£140	£180	£60	£210
Extra Large	£210	£270	£90	£315

Appendix E – Knowsley Safari Case Study

CAPEX Estimate

Estimated costs breakdown for fabric retrofit

Building Reference	Building Size	Insulation	Draught Proofing	General Building Maintenance	Total
Rhino House A	Large	£800	£210	-	£1010
Rhino House B	Large	£800	-	-	£800
Bongo House	Small	£100	-	-	£100
Lion House	Medium	-	-	-	-
Animal Office	Medium	£400	£105	-	£505
Giraffe House	Extra Large	£1200	£315	£1000	£2515
Hog House	Small	£100	-	-	£100
Tapir House	Small	£100	-	-	£100
Sea Lion House	Extra Large	£450	-	-	£450
Oasis Restaurant	Large	£300	£210	-	£510
Discovery Centre	Medium	£150	-	-	£150
Gift Shop	Medium	£150	-	-	£150
Total	-	£4550	£840	£1000	**£6390**

Appendix E – Knowsley Safari Case Study

Annual Energy Savings Estimate

Estimated annual energy savings breakdown for fabric retrofit

Building Reference	Building Size	Insulation	Draught Proofing	General Building Maintenance	Total
Rhino House A	Large	£320	£60	-	£380
Rhino House B	Large	£320	-	-	£320
Bongo House	Small	£60	-	-	£60
Lion House	Medium	-	-	-	-
Animal Office	Medium	£160	£30	-	£190
Giraffe House	Extra Large	£480	£90	£315	£885
Hog House	Small	£60	-	-	£60
Tapir House	Small	£60	-	-	£60
Sea Lion House	Extra Large	£270	-	-	£270
Oasis Restaurant	Large	£180	£60	-	£240
Discovery Centre	Medium	£90	-	-	£90
Gift Shop	Medium	£90	-	-	£90
Total	-	£2090	£240	£315	**£2645**

O&M

Measure	Maintenance Frequency [yrs]	Estimated Cost	Notes
Insulation	10	£1500	Replace or refurbish roof insulation

Draught Proofing	10	£500	Audit required to check for new draughts
General Building Maintenance	10	£1000	Thermal efficiency audit required for buildings
Total		£3000	

Summary

Measure	**CAPEX**	**O&M**	**O&M Frequency**	**Annual Energy Savings**
Insulation	£4550	£1500	10	£2090
Draught Proofing	£840	£500	10	£240
General Building Maintenance	£1000	£1000	10	£315
Total	£6390	£3000	-	£2645

- Assessment Period = 20 years
- CAPEX = £6390
- O&M [20 yrs] = £6000
- Energy Savings [20 yrs] = £52,900

Energy Management System (EMS)

Proposed Measures

a) Dedicated Staff Role
b) Sub-metering
c) Power-factor Correction & Voltage Optimisation

Assumptions

Based on research conducted, data collected, and site energy audit the following recommendations have been made for the implementation of an energy management system (EMS).

EMS Audit

Measure	Approx. Number	Notes
Dedicated Staff Role	1x part-time staff role	- Estimated Salary = £28,000 - Should take approx. 50% of staff time to work on energy efficiency - It is assumed that this role will be able to save 5% on energy bills per year. - Staff role from 2020 - 2025
Sub-meters	18x sub-meters	Estimated cost of meters £71/meter
PFC & VO	3x meters	- Savings calculated using 'Energy Ace' PFC & VO calculators based on bills from Knowsley Safari [1] - Meters considered: Prescott Bypass; Giraffe House; Fun Fair

CAPEX Estimate

Estimated costs breakdown for EMS

Measure	Approx. Number	Cost/Unit	Total CAPEX

Dedicated Staff Role	1x part-time staff role	£14,000	= 1 x £14,000 = £14,000
Sub-Meters	20 x sub-meters	£71	=20 x £71 = £1420
PFC & VO	3x meters	£6978	= 3 x £6,978 = £20,934
Total	-		£36,354

Annual Energy Savings Estimate

Estimated annual energy savings breakdown for EMS

Measure	**Annual Energy Savings**	**Notes**
Dedicated Staff Role	£8,800	- 5% of energy bills. - 2018 energy bills = £176,000
Sub-Meters	£150	- Approx. 10% of CAPEX
PFC & VO	£10,467	- Taken from Energy Ace calculator [1]
Total	£19,417	-

O&M

O&M costs for EMS

Measure	**Maintenance Frequency [yrs]**	**Estimated Cost**	**Notes**
Dedicated Staff Role	1	£14,000	50% of Annual Salary
Sub-Meters	1	£50	Replace batteries and check equipment
PFC & VO	10	£419	5% of CAPEX

Total		£3000	

Summary

Summary Table for EMS

Measure	CAPEX	O&M	O&M Frequency [yrs]	Annual Energy Savings
Dedicated Staff Role	£14,000	£14,000	Every year for 5 years	£8,800
Sub-Meters	£1,420	£50	1	£150
PFC & VO	£20,934	£1,047	10	£10,467
Total	£36,354	£15,097	-	£19,417

- Assessment Period = 20 years
- CAPEX = £36,354
- O&M [20 yrs] = £73,093
- Energy Savings [20 yrs] = £388,340

Lighting & Controls

Proposed Measures

a) To replace all lighting to LEDs
b) PIR Sensors

Assumptions

Lighting audit was conducted to assess current fittings, current energy from lighting was calculated and savings based on audit values.

Lighting Audit

Area	Halogen	Halogen Floods	1/4 Fluorescent tubes (<40cm)	3/4 Fluorescent tubes (70 -	Fluorescent tubes (110 - 140cm)	CFL (4-Pin 3000k)	LED Floodlights	LED Tubes	LED Spots
Restaurant Oasis	7		57	8	14	43		12	45
Rhino House A					16				
Rhino House B					16				
Bongo House					4				
House Bandia								2	
Lion House					12				
Baboon House					2				
Antelope House	12								
Monkey Gap (Staff Hut)					1				
Tower (Surveillance)					2				
Lion Gap (Staff Hut)					1				
Animal Office	5				10				

Elephant House					15				
Giraffe House							3		
Hog House					2				
Tapir House					2				
Meerkat House					3				
Bush Dog House	2								
Sea Lion House	20	5			2				
Bat Forest	2								
Bird of Prey House					13				
Ride Ticket Office					2	4			
Maintenance		5			4		2		
Head Office								10	25
Carousel	120								
Jungle Dodgems							5		
Ice Cream Hut					2				
Grill Hut						1	2		
Cafe Hut					2				
Face Paint Hut					2				
Discovery Centre/ Reptile House					14				
W.C. (near restaurant)					6				
Gift Shop	10				22	7			

Party Rooms					6				
Total	178	10	57	8	175	55	12	24	70

CAPEX Estimate

Estimated costs breakdown for Lighting & Controls

Measure	**Approx. Number**	**Cost/Unit [parts & installation]**	**Total CAPEX**
LED Lighting	LED Spot Lights = 216 LED Tube Lights = 206 LED Flood Lights = 10	LED Spots = £20 LED Tubes = £40 LED Floods = £40	= £12,960
PIR Sensors	28	£17	= £476
Total	-		£13,460

Annual Energy Savings Estimate

Estimated annual energy savings breakdown for Lighting & Controls

Measure	**Annual Energy Savings**	**Notes**
LED Lighting	£10,019	- Current OpEx = £14,168 - LED OpEx = £4,149
PIR Sensors	£800	- In specified areas PIR sensors should reduce operational lighting time from 16 hrs/day to 6 hrs/day
Total	£10,819	-

O&M

O&M Costs for Lighting & Controls

Measure	Maintenance Frequency [yrs]	Estimated Cost	Notes
LED Lighting	10	£1,464	LED bulbs should last for around 20 years, however under heavy use certain fittings may require replacing after 10 years. It has been assumed that 50% of bulbs will need replacing every 10 years. Bulb replacement costs as follows: - LED Spots = £5/unit - LED Tubes = £8/unit - LED Floods = £20/unit
PIR Sensors	n/a	n/a	n/a
Total		£1,464	

Summary

Summary Table for Lighting & Controls

Measure	CAPEX	O&M	O&M Frequency [yrs]	Annual Energy Savings
LED Lighting	£12,960	£1,464	10	£10,019
PIR Sensors	£500	-	-	£800
Total	£13,460	£15,097	-	£10,819

- Assessment Period = 20 years
- CAPEX = £13,460
- O&M [20 yrs] = £2,928
- Energy Savings [20 yrs] = £216,380

HVAC

Proposed Measures

a) HVAC Equipment Audit
b) Infrared (IR) Heating systems to replace all old, inefficient, electrical heating systems
  - Heat Lamps
  - Old IR Panels
  - Halogen Heaters
  - Electric Convection Heaters

Assumptions

An audit was conducted to assess the condition of existing electrical heating systems, lists the buildings that require HVAC upgrades, details there estimated size, and wattage requirements for the installation of IR heating. It is important to note that Tansun IR Heating systems have been used due to their experience of heating animal houses and numerous case studies available on their website; Other manufacturers are available and prices will vary between suppliers.

HVAC Audit

Building Reference	Building Size	Wattage Requirements	IR Heating System Requirements
Rhino House B	300 m^2	36 kW	2x Tansun Apollo A3F
Bongo House	70 m^2	7.4 kW	2x Tansun Apollo A1B
Capybara House	10 m^2	2.3 kW	1x Tansun Apollo A1B
Hog House	10 m^2	4.5 kW	2x Tansun Apollo A1A
Sea Lion House	600 m^2	144 kW	4x Tansun Apollo A3F
Meerkat House	4 m^2	0.7 kW	1x Tansun Apollo A1A
Bat Forrest	80 m^2	17 kW	2x Tansun Apollo A1K
Ride Ticket Office	15 m^2	3.3 kW	2x 3C 300 Cassette Panel

Maintenance	140 m^2	17 kW	2x Tansun Apollo A3K
Discovery Centre	140 m^2	13 kW	3x 3C 850 Cassette Panel
Gift Shop	200 m^2	27 kW	4x 3C 850 Cassette Panel

CAPEX Estimate

Estimated costs breakdown for HVAC

Building Reference	Building Size	Cost/Unit	Units	Total
Rhino House B	300 m^2	£2,000	2	£4,000
Bongo House	70 m^2	£442.8	2	£885.6
Capybara House	10 m^2	£418.8	1	£418.8
Hog House	10 m^2	£262.8	2	£525.6
Sea Lion House	600 m^2	£2,000	4	£8,000
Meerkat House	4 m^2	£238.8	1	£238.8
Bat Forrest	80 m^2	£670.8	2	£1,341.6
Ride Ticket Office	15 m^2	£131.26	2	£262.52
Maintenance	140 m^2	£694.8	2	£1389.6
Discovery Centre	140 m^2	£240.44	3	£721.32
Gift Shop	200 m^2	£240.44	4	£961.76
CONTROLLERS	-	n/a	12	£5,000
INSTALLATION	-	£50	27	£1350
Total	-	-	n/a	**£25,350**

Annual Energy Savings Estimate

- Heating accounts for 40% of electricity consumption.
- Electricity = 40% of £150,000 = £60,000
- IR Heating estimated to save 20% of heating bills by replacing electric heating sources.

Estimated annual energy savings breakdown for HVAC

Energy Source	Calculation	Estimated Annual Savings
Electricity	20% of £60,000	£12,000

O&M

O&M costs for HVAC

Measure	Maintenance Frequency [yrs]	Estimated Cost	Notes
IR Heating	10	£6,338	Replace 25% of systems every 10 years

Summary

Summary Table for HVAC

Measure	CAPEX	O&M	O&M Frequency [yrs]	Annual Energy Savings
IR Heating	£25,350	£6,338	10	£12,000
Total	£25,350	£15,097	-	£12,000

- Assessment Period = 20 years
- CAPEX = £25,350
- O&M [20 yrs] = £12,625
- Energy Savings [20 yrs] = £240,000

Biomass Boiler

Proposed Measures

a) Biomass Boiler
    - Fuel Source: Wood Chip
    - 7 years of RHI Payments

Assumptions

The scenario proposes the installation of 4 biomass systems to replace existing LPG heating systems.

LPG Heating Audit

Building Reference	Required System Size
Rhino House A	Large
Oasis Restaurant	Large
Giraffe House	Large
Main Office	Medium

CAPEX Estimate

Approximated system costs for a large auto-feed biomass system:

- £15,000 – £21,000 (Eco Experts)
- £10,000 - £19,000 (Green Match)
- £14,000 - £19,000 (Renewable Energy Hub)
- £9,000 system can produce 25,000 kWh (green square)
- Installation Costs = £5,000 - £25,000 (Renewable Energy Hub, Eco Experts)

System Size	Boiler Cost	Installation Cost

Large	£20,000	£10,000
Medium	£15,000	£6,000

Estimated costs breakdown for HVAC

Building Reference	System Size	Boiler Cost	Installation Cost	Total
Rhino House A	Large	£20,000	£10,000	£30,000
Oasis Restaurant	Large	£20,000	£10,000	£30,000
Giraffe House	Large	£20,000	£10,000	£30,000
Main Office	Medium	£15,000	£6,000	£21,000
Total	-	£75,000	£36,000	**£111,000**

Annual Energy Savings Estimate

RHI Payments

- 3.11 p/kWh for small biomass (less than 200 kWth) – Non-Domestic
- Available for 7 years

RHI Payments for Biomass Boiler

Building Reference	Annual Heating Demand	Annual RHI Payment
Rhino House A	121,000 kWh	£3,763.10
Oasis Restaurant	150,000 kWh	£4,665.00
Giraffe House	175,000 kWh	£5,442.50
Main Office	54,000 kWh	£1,679.40

Total	500,000 kWh	£15,550

Savings

- LPG = 4.2 p/kWh
- Wood Chip = 2.9 p/kWh

Estimated annual energy savings breakdown for Biomass

Building Reference	**Annual Heating Demand**	**LPG Fuel Costs**	**Wood Chip Fuel Costs**	**Savings**
Rhino House A	121,000 kWh	£5,082	£3,509	£1,573
Oasis Restaurant	150,000 kWh	£6,300	£4,350	£1,950
Giraffe House	175,000 kWh	£7,224	£4,988	£2,236
Main Office	54,000 kWh	£2,268	£1,566	£702
Total	500,000 kWh	£20,874	£14,413	£6,461

O&M

O&M costs for HVAC

Measure	**Maintenance Frequency [yrs]**	**Estimated Cost**	**Notes**
Fuel Cost	1	£14,413	Estimated cost for the supply of wood chips
Annual Maintenance to systems	1	£2,200	2% of CAPEX

Appendix E – Knowsley Safari Case Study

Summary

Summary Table for HVAC

Building Reference	CAPEX	O&M	O&M Frequency [yrs]	Annual Energy Savings
Rhino House A	£30,000	£4,109	1	£5,336.10
Oasis Restaurant	£30,000	£4,950	1	£6,615.00
Giraffe House	£30,000	£5,588	1	£7,678.50
Main Office	£21,000	£1,986	1	£2,381.40
Total	£111,000	£16,633	-	£22,011.00

- Assessment Period = 20 years
- CAPEX = £111,000
- O&M [20 yrs] = £332,660
- Energy Savings [20 yrs] = £238,850

Solar Farm

Proposed Measures

a) 1MW Solar Farm
   - Should provide enough electricity for the whole site
   - Will require approximately 5-10 acres of land

Assumptions

A 1MW solar farm should provide enough electricity to power the whole site. A battery system has not been included in these calculations but is something that should be considered, consult a specialist for more information solar power with battery storage. Solar panels have an expected lifespan of approximately 30-40 years, however solar panels typically see a decrease in efficiency of approximately 0.5% every year. Inverters are required to convert the DC current generated from the solar panels into AC current in order for electricity to be used or exported.

Solar Farm Cost Breakdown

Solar Farm Component	% of system costs
Solar Panels	35%
Inverters	6%
Mounting Structures	10%
Installation/other costs	24%
Balance of systems	25%

- Balance of systems (BoS) comprises of junction boxes, HV, LV, and DC electrical cables, transformers, switch gear, AC & DC cables, security of systems.

CAPEX Estimate

Approximated system costs for a utility-scale solar power plant of 1MW:

- 2015: £1-£1.2/W, therefore a 1MW system cost approx. £1-1.2m (Solar Mango [2])
- 2019: £0.7-£0.8/W. therefore a 1 MW system cost approx. £7-800,000.

Estimated costs breakdown for 1MW Solar Farm

Solar Farm Component	% of system costs	Estimated cost for 1MW solar farm
Solar Panels	35%	£280,000
Inverters	6%	£48,000
Mounting Structures	10%	£80,000
Installation costs	24%	£192,000
Balance of systems	25%	£200,000
Total	100%	£800,000

Annual Energy Savings Estimate

Estimated savings for 1MW Solar Farm

Savings/Income Source	Savings	Notes
Purchased Grid Electricity	£150,000	Based on current price of electricity, it is likely that energy prices will increase with inflation and therefore savings will be higher each year.
Export Surplus	£5,918	Estimated surplus based on current energy demand = 110,000 kWh/annum. Export Tariff = 5.38 p/kWh

O&M

O&M costs for Solar Farm

Measure	Maintenance Frequency [yrs]	Estimated Cost	Notes
General Maintenance	1	£8,000	According to powerfromsunlight.com general maintenance should account for approx. 1% of project CAPEX
Inverter Replacement	15	£48,000	6% of CAPEX [2]

Summary

- Assessment Period = 20 years
- CAPEX = £800,000
- O&M [20 yrs] = £208,000
- Energy Savings [20 yrs] = £2,910,360

Anearobic Digestion & CHP

Proposed Measures

a) AD CHP to provide heat and electricity to the site
  - Fuel Source: Animal waste + imported maize
  - 7 years of RHI Payments

Assumptions

The scenario proposes the installation of 1 large, centralised anaerobic digestor (AD) to provide biogas for a combined heat and power plant (CHP). Knowsley Safari consumes approx. 83 MWh each month, costing around £12,500/month. Based on current energy demand Knowsley Safari will require a 125 kWe AD CHP plant to provide 50% of the required electricity and 100% of the required heat.

CAPEX Estimate

Approximated system costs for a 125 kWe AD CHP system:

AD CHP system breakdown

System Component	Estimated Cost
Anaerobic Digestor	£350,000
Generator/ CHP	£150,000
Gas Treatment	£10,000
Backup Boilers	£12,000
WPF-LC Interconnector	£90,000
DNO Export Agreement	£7,500
Total	£627,000

Annual Energy Savings Estimate

RHI Payments

- 2.88 p/kWh for small biogas combustion (less than 200 kWth) – Non-Domestic
- Available for 7 years

System	Annual Heating Demand (LPG)	Annual RHI Payment
125 kWe AD CHP	400,000 kWh	£11,520

Savings

- LPG = 4.2 p/kWh

Estimated annual energy savings breakdown for AD CHP

Saving/income Source	Annual Savings/Income	Notes
Electricity	£75,000	50% of electricity requirements
LPG	£20,800	100% of all heat provided from LPG. Heat from LPG accounts for approx. 80% of total bill.
Surplus Export	£2,500	Based on an estimated surplus of 50,000 kWh. Export Tariff @ 5 p/kWh
RHI	£11,520	RHI payments @ 2.88 p/kWh
Total	£109,820	-

O&M

O&M costs for AD CHP

Measure	Maintenance Frequency [yrs]	Estimated Cost	Notes
Maize silage (fuel)	1	£36,000	Fuel source to the AD. AD converts this to a usable biogas.
Digester & CHP maintenance	1	£13,000	Require annual maintenance and routine checks to maintain efficiency.
Labour	1	£7,500	-
Insurance	1	£1,500	-
Total	-	£58,000	-

Summary

- Assessment Period = 20 years
- CAPEX = £109,820
- O&M [20 yrs] = £1,160,000
- Energy Savings [20 yrs] = £3,816,040

Wind Turbine

Proposed Measures

a) 800 kW wind turbine
  - Should provide enough electricity for the whole site
  - Wind speed audit is required
  - Ecology assessment needed

Assumptions

An 800-kW wind turbine should easily provide the required energy demand to the site based on an average wind speed of 6 m/s. A wind assessment is required to see whether the turbine can be placed in a suitable location to achieve the required energy generation. Knowsley Safari uses approx. 1,000,000 kWh of electricity annually.

- **Enercon E48 800 kW – AEP @ 6m/s = 1,700,000 kWh**
- Enercon E53 800 kW – AEP @ 6m/s = 2,000,000 kWh
- EWT DW54 900 kW – AEP @ 6m/s = 1,508,000 kWh
- Norvento nED100 – AEP @ 6m/s = 478,000 kWh [3]

CAPEX Estimate

Approximated system costs for wind turbines:

Estimated CAPEX for wind turbines or varying sizes

Turbine Name	Estimated CAPEX
Enercon E48	£1,000,000
Enercon E53	£1,400,000
Norvento nED100	£345,000
EWT DW54	£1,250,000

N.B. Enercon E48 was used in calculations and other options have been included for reference.

Annual Energy Savings Estimate

Estimated savings for 800 kW wind turbine

Savings/Income Source	**Savings**	**Notes**
Purchased Grid Electricity	£150,000	Based on current price of electricity, it is likely that energy prices will increase with inflation and therefore savings will be higher each year.
Export Surplus	£37,660	Estimated surplus based on current energy demand = 700,000 kWh/annum. Export Tariff = 5.38 p/kWh

O&M

O&M costs for wind turbines

Measure	**Maintenance Frequency [yrs]**	**Estimated Cost**	**Notes**
General Maintenance	1	£41,000	Based on research conducted by Renewables First [3]

Summary

- Assessment Period = 20 years
- CAPEX = £1,000,000
- O&M [20 yrs] = £820,000
- Energy Savings [20 yrs] = £3,753,200

Solar Thermal

Proposed Measures

a) Solar Thermal systems to be installed on certain buildings to provide hot water only.
    - 7 years of RHI Payments

Assumptions

A number of domestic sized solar collectors to be installed on the following buildings:

Solar thermal system audit

Building Reference	No. of Collectors
Animal Office	1
Maintenance	1
Main Office	2
Oasis Restaurant	6-8
WC	2

- Solar thermal systems include the following components: Solar collectors, control panels, pipes, hot water tank.
- Prices and energy outputs have been calculated for a twin coil, evacuated tube solar thermal system.
- Typical output of a domestic solar thermal installation in the UK is between 1000 - 2500 kWh [4].
- Solar thermal systems can typically provide:
    - 100% of hot water needs in Apr, May, Jun, Jul, Aug, Sep
    - 75% in Mar & Oct
    - 50% in Nov & Feb
    - 25% in Jan & Dec

CAPEX Estimate

- It is expected to pay around £3-6000 for domestic sized solar thermal systems according to research conducted by the Renewable Energy Hub [4]. Based on this an average of £4,500/system has been used to calculate CAPEX.

Approximated system costs for evacuated tube solar collectors:

Solar thermal system costs

Building Reference	No. of Collectors	Cost
Animal Office	1	£4500
Maintenance	1	£4500
Main Office	2	£9000
Oasis Restaurant	6	£27,000
WC	2	£9000
Total	12	£54,000

Annual Energy Savings Estimate

RHI Payments

- 10.98 p/kWh for Solar collectors (less than 200 kWth) – Non-Domestic
- Available for 7 years

Solar thermal RHI payments

Building Reference	Estimate heat output	RHI Payments
Animal Office	2,500 kWh	£274.50
Maintenance	2,500 kWh	£274.50

Main Office	5,000 kWh	£549.00
Oasis Restaurant	15,000 kWh	£1,647.00
WC	5,000 kWh	£549.00
Total	30,000 kWh	£3294

Fuel Savings

- LPG = 4.2 p/kWh
- Electricity = 16 p/kWh

Solar thermal fuel savings

Building Reference	Estimate heat output	Original energy source	Fuel savings
Animal Office	2,500 kWh	Electricity	£400
Maintenance	2,500 kWh	Electricity	£400
Main Office	5,000 kWh	LPG	£210
Oasis Restaurant	15,000 kWh	LPG	£630
WC	5,000 kWh	Electricity	£800
Total	30,000 kWh		£2,440

O&M

There are very few O&M costs with domestic sized solar thermal systems, the collectors have a lifespan of around 20-30 years. Smaller components such as the heat pump may need replacing every 10 years, however this is a relatively inexpensive part to replace. It is assumed that maintenance will be required once a year at 1% of the CAPEX.

CAPEX = £54,000, therefore O&M = £540/annum

Summary

- Assessment Period = 20 years
- CAPEX = £54,000
- O&M [20 yrs] = £10,800
- Energy Savings [20 yrs] = £ 71,858

Ground Source Heat Pump (GSHP)

Proposed Measures

a) To install a GSHP to provide hot water and minor heating to certain buildings.
   - 7 years of RHI Payments
   - Feasibility study will be required to decide upon type of system, whether it be a borehole, closed loop, open loop, or a water source heat pump (WSHP)

Assumptions

For the purpose of this report, it is assumed a closed loop ground source heat pump is installed to provide hot water and minor heating requirements to the following buildings:

GSHP audit

Building Reference	Use
Animal Office	Hot water & space heating
Rhino House A & B	Space heating

- It is important to note that heat pumps do require an electrical supply and so to be 100% renewable it would be preferable for the power to come from a renewable energy source, whether it be solar panels, or a wind turbine etc.
- GSHP benefit from the RHI.
- If installed in an efficient building it could significantly reduce energy bills, despite the fact it requires electricity to power the pump.
- GSHP deliver heat at much lower temperatures than regular gas or electric systems and so therefore combining it with underfloor heating is a more efficient solution, however, it will significantly add to the costs.
- GSHP require little to no maintenance and the ground collectors have an expected lifespan of around 70 years.

CAPEX Estimate

- To calculate CAPEX for GSHPs, it is estimated that 1.1 kWh of energy used will cost around £1, so for a system to produce 11,000 kWh it would cost approx. £10,000.

Approximated system costs for 4 GSHPs to be installed at the following locations:

GSHP system costs

Building Reference	Energy Requirements	System Cost
Animal Office	11,800 kWh	£10,700
Rhino House A & B	133,300 kWh	£121,000
Total	145,100 kWh	£131,700

Annual Energy Savings Estimate

RHI Payments

- 9.56 p/kWh for GSHPs (All capacities) – Non-Domestic
- Available for 7 years

GSHP RHI payments

Building Reference	Estimate heat output	RHI Payments
Animal Office	11,800 kWh	£1,128
Rhino House A & B	133,300 kWh	£12,743
Total	145,100 kWh	£13,871

Fuel Costs & Savings

- LPG = 4.2 p/kWh
- Electricity = 16 p/kWh
- Typical heat pump COP is 4, therefore for every kW of electricity used 4 kW of heat is produced

GSHP fuel savings

Building Reference	Estimate heat output	Estimated electricity usage from heat pump	Original energy source	Original OpEx	Heat pump OpEx	Fuel Savings
Animal Office	11,800 kWh	2,950 kWh	Electricity	£1,888	£472	£1416
Rhino House A & B	133,300 kWh	33,325 kWh	LPG & Electricity	£7,050	£5,332	£1718
Total	145,100 kWh	36,275 kWh	-	£8,938	£5,804	**£3134**

O&M

There are very few O&M costs with GSHPs and a simple annual inspection of the heat pumps is all that is required, this has been factored into the CAPEX, for the purposes of these calculation there are zero O&M costs. However, it is recommended to contact a heat pump specialist for more detailed maintenance plans.

Summary

- Assessment Period = 20 years
- CAPEX = £131,700
- O&M [20 yrs] = n/a
- Savings [20 yrs] = £ 181,715

Air Source Heat Pump (ASHP)

Proposed Measures

a) To install an ASHP to provide heating to a number of buildings.
   - 7 years of RHI Payments

Assumptions

It is assumed that air to air systems are installed due to the increased capital requires for air to water systems. This is because most of the existing buildings operate dry heating systems through space heating techniques.

The following buildings have been considered for ASHP installation:

ASHP audit

Building Reference	Current System
Animal Office	Electric convection heaters
Discovery Centre	Electric convection heaters & heat lamps
Bat Forrest & Maintenance	Old IR panels & electric space heaters
Tapir House	Old IR panel heaters

- It is important to note that heat pumps do require an electrical supply and so to be 100% renewable it would be preferable for the power to come from a renewable energy source, whether it be solar panels, or a wind turbine etc.
- ASHP benefit from the RHI.
- If installed in an efficient building it could significantly reduce energy bills, despite the fact it requires electricity to power the pump.
- ASHP deliver heat at much lower temperatures than regular gas or electric systems and so therefore combining it with underfloor heating is a more efficient solution, however, it will significantly add to the costs.
- A cheaper and easier option to GSHPs.

CAPEX Estimate

- ASHPs typically cost between £3-14,000 depending on the size of the building and the heating requirements.

Approximated system costs for 4 ASHPs to be installed at the following locations:

ASHP system costs

Building Reference	Energy Requirements	System Cost
Animal Office	11,800 kWh	£5,000
Discovery Centre	24,400 kWh	£10,000
Bat Forrest & Maintenance	25,000 kWh	£10,000
Tapir House	16,000 kWh	£7,000
Total	349,100 kWh	£32,000

Annual Energy Savings Estimate

RHI Payments

- 2.75 p/kWh for ASHPs (All capacities) – Non-Domestic
- Available for 7 years

ASHP RHI payments

Building Reference	Estimate heat output	RHI Payments
Animal Office	11,800 kWh	£325
Discovery Centre	24,400 kWh	£671

Bat Forrest & Maintenance	25,000 kWh	£688
Tapir House	16,000 kWh	£440
Total	349,100 kWh	£2,124

Fuel Costs & Savings

- LPG = 4.2 p/kWh
- Electricity = 16 p/kWh
- Typical heat pump COP is 4, therefore for every kW of electricity used 4 kW of heat is produced

ASHP fuel savings

Building Reference	Estimate heat output	Estimated electricity usage from heat pump	Original energy source	Original OpEx	Heat pump OpEx	Fuel Savings
Animal Office	11,800 kWh	2,950 kWh	Electricity	£1,888	£472	£1,416
Discovery Centre	24,400 kWh	6,100 kWh	Electricity	£3,904	£976	£2,928
Bat Forrest & Maintenance	25,000 kWh	6,250 kWh	Electricity	£4,000	£1,000	£3,000
Tapir House	16,000 kWh	4,000 kWh	Electricity	£2,560	£640	£1,920
Total	30,000 kWh	19,300 kWh	-	£12,352	£3,088	**£3542**

O&M

- ASHPs require professional maintenance around every 3-5 years and should be serviced by a technician once a year. It has been assumed that servicing of 4 systems would cost approximately £500/annum.

Appendix E – Knowsley Safari Case Study

Summary

- Assessment Period = 20 years
- CAPEX = £32,000
- O&M [20 yrs] = £10,000
- Savings [20 yrs] = £85,708

Ultra-Low Emissions Vehicles (ULEVs)

Proposed Measures

a) Proposed solution is to replace 10 of the current fleet vehicles with ultra-low emissions vehicles (ULEVs)
   - Hybrid & Fully Electric Vehicles

Assumptions

- It is assumed that the average cost of a new hybrid or 100% electric vehicle is around £30,000.
- At present (Autumn 2019) Knowsley Safari only have one hybrid vehicle in their fleet which is a service vehicle with relatively low mileage
- In addition to ULEVs, charging points should be installed on the site and powered via a renewable source of energy.
- The aim would be to replace all petrol & diesel vehicles with hybrid or electric vehicles by at least 2030 if not before.
- EV charge points should be made available for visitors and could generate an income by charging customers to charge their cars. This would also encourage guests to stay at the park longer, and are likely to spend more money in the process.

CAPEX Estimate

ULEV CAPEX estimate

Measure	**Units**	**Cost/Unit**	**Total**
Hybrid & EVs	10	£30,000	£300,000
Charge Points	10	£1,000	£10,000
Total	-	-	£310,000

Annual Energy Savings Estimate

Fuel Costs & Savings

- MPG = Miles per gallon
- MPGe = Miles per gallon equivalent
- All values in table taken from Fleet News to ensure a fair comparison

Appendix E – Knowsley Safari Case Study

ULEV vs. petrol & diesel running costs

Car Type	Example Car	MPG/ MPGe	Cost	Fuel Cost/mile	Annual Fuel Costs at 10,000 miles
Electric	Nissan Leaf	112	£31,440	5.87 p	£587
Electric	Kia e-Niro	112	£36,495	4.25 p	£425
Hybrid	Toyota Prius	67.3	£23,449	8.65 p	£865
Hybrid	Mitsubishi Outlander PHEV	139	£37,700	7.87 p	£787
Diesel	Land Rover Discovery	33.6	£46,110	17.84 p	£1784
Diesel	Ford Focus Estate Diesel	60.1	£20,740	9.98 p	£998
Petrol	Peugeot 208	51.5	£16,250	11.29 p	£1129

Approximate annual fuel savings of around £500-1500 depending on vehicle size and fuel source. An average of £1000 per car is taken for this calculation.

$$\therefore\ 10\ \text{cars x}\ £1000 = £10{,}000/\text{annum}$$

It is important to note that if electric vehicles are charged via renewable energy generated on-site, then the fuel cost per mile will significantly decrease and savings will be much higher.

O&M

It is likely that O&M costs will be much less for electric and hybrid cars as electric engines have very little mechanical moving parts. Due to this, they are expected to be more reliable that traditional petrol & diesel cars.

Summary

- Assessment Period = 20 years
- CAPEX = £310,000
- O&M [20 yrs] = n/a
- Savings [20 yrs] = £200,00

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