A Holistic Approach to Addressing Environmental Sustainability in Data Centres

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Abstract

The exponential growth in data centres, driven by increasing demands for data storage and processing, has led to significant environmental concerns. Data centres are estimated to consume between 2% and 4% of the world's electricity, highlighting the urgent need for effective sustainability assessment methods. While various approaches, best practices, and key performance indicators (KPIs) have been proposed to address this issue, a comprehensive assessment approach tailored specifically for data centres remains lacking. Existing schemes such as LEED and BREEAM, initially designed for the building construction industry, are being increasingly adopted by data centres. However, these schemes primarily focus on building aspects, with insufficient emphasis on mechanical, electrical, and IT components.

This research comprehensively analyses the LEED certification scheme, one of the most widely used sustainability assessment frameworks. It investigates the attainment patterns and growth trends of data centres pursuing LEED certification, evaluates their performance in achieving LEED credits, and identifies the gaps and limitations of the current framework when applied to data centres. The study reveals that many LEED credits are attained based on ease and cost rather than substantial environmental savings, contributing to potential greenwashing.

By applying the proposed model to several case studies of data centres of varying sizes and locations, the research demonstrates that energy credits, particularly those related to renewable energy, contribute significantly to overall savings. However, the findings also indicate that each data centre's unique characteristics lead to different savings contributions, underscoring the inadequacy of a uniform approach.

The results highlight the need for a more tailored LEED certification framework that better reflects data centres' actual environmental impact and operational requirements. The proposed categorised scoring scheme or weighted approach offers a more accurate sustainability assessment. When applied to currently certified data centres, this new scheme better aligns with actual savings and environmental impact, promoting genuine sustainability in the data centre industry.

This research provides valuable insights for stakeholders, including data centre operators, sustainability consultants, and policymakers, enabling them to implement more effective sustainability practices and develop more accurate policies and standards.

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List of Abbreviations

AI	Artificial Intelligence
ANSI	American National Standards Institute
ASHRAE	American Society of Heating, Refrigerating and Air-Conditioning Engineers
AWS	Amazon Web Services
BREEAM	Building Research Establishment Environmental Assessment Method
BSI	British Standards Institution
CAGR	Compound Annual Growth Rate
CEEDA	Certified Energy Efficient Datacentre Award
CEN	European Committee for Standardization
CPP	Clean Power Plan
CSRD	Corporate Sustainability Reporting Directive
CDC	Control Data Corporation
DCOI	Data Centre Optimisation Initiative
DEEP	Data Centre Energy Efficiency Program
EED	Energy Efficiency Directive

EERE Office of Energy Efficiency and Renewable Energy

EN European Norm

EPA Environmental Protection Agency

ETS Emissions Trading System

EU European Union

EU GPP European Union Green Public Procurement

FYP Five Years Plan

GHG Greenhouse Gas

ICT Information and Communication Technology

IoT Internet of Things

IRA Inflation Reduction Act

ITU International Telecommunication Union

ISO International Organization for Standardization

IT Information Technology

KPI Key Performance Indicator

KSA Kingdom of Saudi Arabia

LAN Local Area Network

LCA Life Cycle Assessment

LEED	Leadership in Energy and Environmental Design
MEA	Middle East and Africa
NAPCC	National Action Plan on Climate Change
PAS	Percentage Average Score
PIF	Public Investment Fund
PUE	Power Usage Effectiveness
WAN	Wide Area Network
RED	Renewable Energy Directive
REF	Renewable Energy Factor
REPower	Renewable Energy Power
RFS	Renewable Fuel Standards
RICS	Royal Institution of Chartered Surveyors
SSPP	Strategic Sustainability Performance Plan
SPP	Sustainability Public Procurement
SWOT	Strengths, Weaknesses, Opportunities, and Threats
UAE	United Arab Emirates
U.S	United States
U.S DoE	United States Department of Energy

USGBC	United States Green Building Council
UNFCCC	United Nations Framework Convention on Climate Change

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Chapter 1. Introduction

1.1 Motivation

The world has witnessed a significant increase in environmental awareness in recent years, as evidenced by the growing public concern over climate change. This heightened consciousness has led to a greater sense of obligation and responsibility among individuals, governments, and organisations to take concrete actions. This shift has had far-reaching implications, particularly in the realm of digital infrastructure, where the exponential rise in data centres and internet usage, driven by the proliferation of technologies like Artificial Intelligence (AI) and the Internet of Things (IoT), has placed an unprecedented strain on energy resources and the environment.

Data centres, the backbone of our digital world, have become a significant contributor to global energy consumption and carbon footprint. As the demand for data storage, processing, and transmission continues to soar, the energy-intensive nature of these facilities has become a pressing concern. The increased adoption of emerging technologies, such as AI and IoT, along with the surge in internet usage during the COVID-19 pandemic, has further exacerbated the demand for energy-efficient and sustainable data centres. Environmental awareness and the obligation to address this issue have never been more pressing.

Currently, data centres are responsible for a substantial portion of global energy consumption, with estimates suggesting they account for 2 to 4% of the world's total power usage (Zhu, et al., 2023). As the digital landscape evolves, the data centre industry must prioritise energy-efficient and sustainable practices to mitigate the strain on natural resources and reduce greenhouse gas emissions. Numerous efforts have been made to address the environmental sustainability of data centres, including the development of various approaches, best practices, and key performance indicators.

Holistic approaches such as Leadership in Energy and Environmental Design (LEED) [1]and Building Research Establishment Environmental Assessment Method (BREEAM) [2]have introduced schemes for assessing the sustainability of data centres (BREEAM, 2012) (USGBC, 2024). Initially designed for the building construction industry, LEED and BREEAM are increasingly being adopted in data centres. LEED, in particular, has gained global recognition and is facing increased adoption from the industry. However, the complexities of data centre operations and the unique requirements of these facilities pose significant challenges in effectively applying LEED standards to assess their environmental sustainability comprehensively.

[1] LEED certification information is available from the U.S. Green Building Council (USGBC) at https://www.usgbc.org/leed.

[2] BREEAM certification details can be accessed from the Building Research Establishment (BRE) at https://www.breeam.com.

1.2 Objectives and Research Question

The primary objective of this study is to evaluate the effectiveness and reflectance of the LEED certification in assessing the environmental sustainability of data centres. This research seeks to identify the attainment patterns and growth trends of data centres approaching LEED certification. It seeks to understand their performance in achieving LEED credits. Additionally, the study proposes tailored approaches to better address their unique operational characteristics. The study aims to contribute to the development of a more robust and comprehensive sustainability assessment framework that can be effectively utilised by the data centre industry.

To achieve this objective, the following research questions are posed:

R.Q.1 - What are data centres' attainment patterns and growth trends approaching LEED certification, considering geographical regions, year of certification, and certification levels?

R.Q.2 - How do data centres perform in achieving LEED credits, and what factors influence the attainability of these credits?

R.Q.3- What are the maximum savings potential of environmental credits in LEED?

R.Q.4- Are these savings reflected correctly in the current LEED scoring system?

R.Q.5- How can the LEED scoring scheme be amended to reflect better the actual environmental savings and contributions of data centres?

R.Q.6- How can the LEED credits be adjusted to consider data centres differently than other buildings, better reflecting their unique environmental impacts and operational characteristics?

R.Q.7- Do the new scoring schemes better reflect data centre environmental savings?

1.3 Contribution

This research makes several significant contributions to the field of environmental sustainability assessment for data centres:

- **Impact Evaluation of Credit:** The research provides a detailed evaluation of the impact and savings potential of environmental credits within the LEED certification system specifically for data centres. By examining the effectiveness of various credits, the study identifies which credits provide the most significant contributions to environmental sustainability and emissions savings. This evaluation highlights the credits that offer the highest environmental benefits, offering valuable insights to prioritise impactful credits. This contribution is particularly significant for data centres, helping them to achieve better environmental performance and align with the most effective sustainable practices within the LEED framework.
- **Comprehensive Evaluation of LEED Effectiveness:** The study provides a detailed evaluation of the LEED certification's effectiveness in assessing the environmental sustainability of data centres. By identifying specific gaps and limitations, the research highlights the areas where LEED can be improved to reflect the unique characteristics of data centres better.
- **Proposed Tailored Approaches:** Based on the identified gaps, the research proposes tailored approaches that modify and enhance the LEED framework to address the unique environmental and operational aspects of data centres. These tailored approaches are designed to ensure that sustainability assessments are more accurate and reflective of actual performance.

1.4 Thesis Outline

This thesis is structured as follows:

Chapter 1: Introduction - This chapter introduces the research topic, outlines the motivation, objectives, research questions, and contributions of the study.

Chapter 2: Literature Review - This chapter reviews the existing literature on environmental sustainability, data centres, and sustainability assessment frameworks such as LEED and BREEAM. It identifies the research gap that this study aims to fill.

Chapter 3: Research Methodology - This chapter describes the research design, methods, and data collection techniques used in this study. It explains the rationale behind the chosen methodology and how it aligns with the research objectives.

Chapter 4: Presents the Meta-Analysis and Statistical Analysis of Credits Attained - This chapter presents a meta-analysis and statistical analysis of the LEED credits attained by data centres, addressing the first two research questions related to attainment patterns, growth trends, and factors influencing credit achievement.

Chapter 5: Demonstrate Model and Calculations of Maximum Savings by Environmental Credit - This chapter develops a model and performs calculations to determine the maximum savings potential of environmental credits.

Chapter 6: Addresses Gaps and Proposes New Scoring Schemes - This chapter identifies gaps in the current LEED scoring system and proposes new scoring schemes to better reflect the environmental sustainability of data centres.

Chapter 7: Validation - This chapter validates the proposed scoring schemes by applying them to previously assessed certified cases, comparing the results to actual impacts.

Chapter 8: Conclusion and Recommendations - This chapter summarises the key findings of the study, discusses the practical implications, and provides recommendations for the data centre industry and policymakers. It also outlines directions for future research.

Chapter 2. Literature Review

2.1 Introduction

The environmental sustainability is a topic of increasing relevance, with businesses and policymakers seeking ways to minimise the environmental impact of their facilities and operations. Governments worldwide strive to achieve net zero ambitions by the end of the decade. However, this pursuit poses a formidable challenge for numerous sectors, including the digital infrastructure industry.

In recent years, there has been a growing concern about the environmental impact of data centres, particularly in relation to their energy consumption and carbon emissions. This concern has been driven by the exponential growth of digital technologies and the increasing reliance on data centres to store, process, and transmit vast amounts of data (Murino, et al., 2023). Sustainability is of paramount importance when it comes to data centres, as their energy consumption and carbon emissions have a significant impact on the environment. As the demand for digital technologies continues to grow, so does the need for sustainable practices within data centres to mitigate their environmental footprint.

This literature review explores the global evolution of environmental sustainability, data centres' growth, data centres' sustainability and existing standards, and challenges related to holistic approaches in achieving sustainability within data centres. It explores gaps in current research and environmental approaches utilised in the data centre industry.

2.2 Environmental Sustainability Global Regulations Evolution

Climate change is undeniably one of the most pressing challenges facing the world today, primarily due to the escalating greenhouse gas emissions. The onset of the Industrial Revolution saw a significant increase in human contributions to climate change. Global GHG emissions have continued to rise consistently for the past decade, reaching 53.8 Gt CO_2 eq in 2022 (JRC/IEA, 2023). As emissions continue to soar, addressing environmental sustainability has emerged as a paramount concern.

In response to this global challenge, various international agreements, such as the Paris Agreement, have been established to tackle the issue of climate change. The Paris Agreement, formulated in 2015, is a landmark because it is the first binding agreement that brings all nations together to combat climate change and adapt to its effects. This international accord aims to limit global warming to well below 2 degrees Celsius above pre-industrial levels, with an ambition to pursue efforts to limit the temperature increase to 1.5 degrees Celsius. It seeks to unify global efforts to mitigate the effects of climate change, promote sustainable development, and ensure a healthier environment for future generations (UNFCCC, 2015).

To address the impacts of climate change, the global aim is to achieve net zero carbon emissions by around the year 2050 (Net Zero Climate, 2024). In response to the Paris Agreement and other influential factors, many governments have created or strengthened regulations to reduce carbon emissions and promote environmental sustainability. Countries across Europe, America, Asia, and the Middle East have declared ambitions to reach net zero by 2050 or 2060 (UNFCC, 2023). Various regulations and acts have been introduced to meet these goals, showing a strong commitment to sustainability. This section introduces some of the nation's sustainability ambitions and regulations.

2.2.1 Overview of European Union (EU) General Sustainability Plans and Directives

Before the Paris Agreement and the introduction of the Green Deal, which has been playing a significant role in the EU, the EU had a role in ensuring an environmental sustainability roadmap. One regulation was the EU Climate and Energy package introduced in 2008. This package, also known as the 20-20-20 targets, aimed to reduce greenhouse gas emissions by 20%, increase the share of EU energy consumption produced from renewable resources to 20%, and improve energy efficiency by 20% by 2020. This package includes the Renewable Energy Directive, Energy Efficiency Directive and Emission Trading System, which are now revised and addressing the Green Deal (EU Commission, 2015).

The Renewable Energy Directive (RED), initially established in 2009, set a target for the EU to achieve 20% of its energy from renewable sources by 2020. This directive was revised to set a new target of 32% by 2030 under the updated framework aligned with the Fit for 55 packages (EU Commission, 2015; EU Commission, 2024a).

The Energy Efficiency Directive (EED), introduced in 2012, set measures to ensure the EU met its 20% energy efficiency target by 2020. This directive was revised in 2021 as part of the Fit for 55 packages to further encourage energy efficiency measures. The revised directive aims to reduce energy consumption and aligns with the EU's target of reducing greenhouse gas emissions, pushing beyond the 2030 target set in 2018 (EU Commission, 2024b; EU Commission, 2015).

The Emissions Trading System (ETS), launched in 2005, was the world's first major carbon market. It aimed to reduce greenhouse gas emissions by setting a cap on the total emissions allowed from high-emitting sectors and enabling companies to trade emission allowances. The ETS has undergone several phases of development and reform to improve its effectiveness and alignment with the EU's climate goals, including a gradual phasing-out of free allowances for some sectors (EU Commission, 2015; EU Commission, 2023a).

Moving forward to 2019, the comprehensive plan is aiming to make the EU's economy sustainable by turning climate and environmental challenges into opportunities. The Green Deal is designed to help the EU achieve its net zero ambitions by 2050 through a series of targeted actions. Several plans, regulations, and directives have been introduced and revised to align with these ambitions, aiming to increase the share of renewable energy, promote energy efficiency, and transition to a circular economy.

As part of the Green Deal, the Fit for 55 package was introduced with the goal of reducing net greenhouse gas emissions by at least 55% by 2030 (EU Commission, 2024c). This package led to the creation and revision of several regulations and directives, including the Energy Efficiency Directive and Energy Taxation Directive. This former directive was introduced in 2012, and in 2021, the directive was revised as part of Fit for 55. ensures that the Fit for 55 and the EU's target of reducing greenhouse gas emissions and going even further beyond the existing 2030 target set in 2018 (EU Commission, 2024d). Targets are redefined regularly, with the latest target being a binding target of at least 11.7% compared to projections of the expected final energy consumption in 2030 compared to the 2020 reference scenario.

In response to shifting to green energy and geopolitical factors, the REPower EU Plan was introduced in 2022. It aims to increase the production of clean energy, diversify energy sources, and promote energy conservation. The share of EU gas coming from Russia was decrease to 15% in 2023 from 45% in 2021. Under this plan, the Energy Solar Strategy was developed, focusing on phasing out fossil fuels and speeding up the transition to green power (EU Commission, 2024a).

Additionally, the European Commission adopted the new Circular Economy Action Plan in March 2020. This plan introduces measures that cover the entire lifecycle of products, emphasising sustainable product design, supporting circular economy practices, encouraging sustainable consumption, and aiming to prevent waste. The goal is to keep resources within the EU economy for as long as possible (EU Commission, 2023b).

Moreover, one important regulation is the EU Taxonomy, which provides a classification system for environmentally sustainable economic activities. It aims to direct investments towards sustainable projects and reduce greenwashing by setting clear criteria for what constitutes a sustainable activity (EU Commission, 2023c). Complementing this, the Green Public Procurement (EU GPP) is a voluntary directive whereby public authorities seek to procure goods, services, and works with a reduced environmental impact throughout their life cycle compared to other options. Although voluntary, EU GPP is related to other mandatory legislation, either recommending GPP or referring to GPP criteria within the existing EU framework (EU Commission, 2021). While these directives are not originally part of the Green Deal, they play a role in being a critical tool for directing the nation towards more sustainable projects and the deal's ambitions.

The next subsection gives and overview of U.S. sustainability acts and programs.

2.2.2 Overview of United States' Sustainability Acts and Programs

Similarly, the United States has a robust history of implementing sustainability regulations, starting well before the Paris Agreement. One of the early legislative efforts was the Energy Policy Act of 2005, which aimed to reduce energy intensities by 2% annually starting from 2006 (EPA, 2023). This act introduced measures to promote energy-efficient technologies and practices, providing a foundational framework for subsequent regulations. Under this act, several programs were authorised, including the Renewable Fuel Standard (RFS) program. Initiated in 2005 and expanded in subsequent years, the RFS mandates the blending of renewable fuels like ethanol and biodiesel into the national fuel supply. This standard aims to reduce greenhouse gas emissions and reliance on imported oil by promoting cleaner, renewable sources of energy (EPA, 2024).

Moreover, the Strategic Sustainability Performance Plan (SSPP) outlines the goals and actions for federal agencies to reduce greenhouse gas emissions, enhance energy efficiency, and integrate sustainability into their operations. Implemented in 2010 and updated annually until 2016, the SSPP focused on achieving significant reductions in energy and water use, advancing renewable energy projects, and promoting sustainable practices (U.S. EPA, 2016).

In 2015, the United States strengthened its commitment to environmental sustainability by joining the Paris Agreement. This commitment included achieving net-zero greenhouse gas emissions by 2050 (UNFCCC, 2015). To meet these goals, the U.S. introduced several key regulations and plans. This includes the Clean Power Plan (CPP), which was introduced in 2015 and was designed to reduce carbon dioxide emissions from power plants by 32% below 2005 levels by 2030. The plan encouraged states to develop their own strategies to meet these targets through renewable energy and energy efficiency measures. It provided guidelines for state plans and included mechanisms such as emissions trading to achieve compliance cost-effectively (EPA, 2016).

However, in 2017, the United States withdrew from the Paris Agreement, citing economic concerns and the potential disadvantages for American businesses and workers. This decision was driven by the belief that the agreement imposed unfair economic burdens on the country, potentially affecting competitiveness and job creation (U.S. Department of State, 2019).

In 2021, the United States rejoined the Paris Agreement, reaffirming its commitment to global climate goals (U.S. Department of State, 2021). Following this re-engagement, the Inflation Reduction Act (IRA) was introduced, marking a significant legislative effort to combat climate change. The IRA is described as one of the most substantial pieces of legislation for climate action in U.S. history, representing a massive investment in clean energy and climate resilience. It aims to catalyse an unprecedented wave of investment and manufacturing in the American economy, driving progress towards the nation's net-zero goals (U.S. Department of Treasury, 2023).

The Inflation Reduction Act includes provisions for substantial funding in renewable energy projects, tax credits and rebates for electric vehicles, support for energy efficiency improvements, and incentives for carbon capture and storage technologies. This comprehensive approach aims to reduce greenhouse gas emissions, promote clean energy, and enhance energy security, positioning the U.S. as a leader in climate action and sustainable development (U.S Department of Energy , 2023).

The following subsection provides an overview of other regions' sustainability plans.

2.2.3 Overview of Global Sustainability Plans

China, as the world's largest emitter of greenhouse gases, has made significant strides in environmental regulation. The country has established carbon trading pilots and implemented various policies and targets to increase the share of non-fossil fuels in primary energy consumption. China's approach to sustainability is embedded in its Five-Year Plans (FYPs). The 13th FYP (2016-2020) emphasised green development, setting targets for reducing carbon intensity, improving air and water quality, and expanding renewable energy capacity (Central Committee of the Communist Party of China, 2016). The 14th FYP (2021-2025) continues this trajectory with a focus on achieving peak carbon emissions by 2030 and carbon neutrality by 2060 (Fujian Gov, 2021). Major initiatives include large-scale investments in renewable energy, electric vehicles, and energy efficiency improvements.

India's National Action Plan on Climate Change (NAPCC), launched in 2008, encompasses eight national missions aimed at promoting sustainable development. These missions include the National Solar Mission, which aims to increase solar energy capacity, the National Mission for Enhanced Energy Efficiency, the National Mission on Sustainable Habitat, the National Water Mission, the National Mission for Sustaining the Himalayan Eco-system, the National Mission for a Green India, the National Mission for Sustainable Agriculture, and the National Mission on Strategic Knowledge for Climate Change (DST, 2024). India aims to achieve carbon neutrality by 2070.

Japan has set an ambitious environmental goal to achieve carbon neutrality by 2050. The country's approach is outlined in several key strategic documents and plans that focus on promoting renewable energy, enhancing energy efficiency, and fostering innovation in green technologies. Key strategies include the expansion of offshore wind power, the development of hydrogen energy infrastructure, and the implementation of carbon capture and storage technologies. The roadmap emphasises the role of public and private sector collaboration in achieving these ambitious targets (METI, 2021).

In the Middle East, countries have taken diverse approaches to environmental regulation. For instance, Saudi Vision 2030 is a comprehensive plan launched in 2016 aimed at diversifying the Saudi economy and reducing its dependence on oil. The vision encompasses various initiatives focused on economic, social, and environmental sustainability. Key environmental goals include increasing the share of renewable energy in the energy mix to 50% by 2030, reducing carbon emissions, and promoting sustainable practices across various sectors (Vision 2030, 2016).The Public Investment Fund (PIF) plays a crucial role in driving Saudi Arabia's sustainability initiatives. PIF's strategy includes significant investments in renewable energy projects, such as the NEOM smart city project, which aims to be powered entirely by renewable energy. PIF is also investing in green hydrogen production and large-scale solar and wind projects to support the Kingdom's transition to a sustainable energy future (Vision 2030, 2021).

Moreover, the UAE Energy Strategy 2050 presents a comprehensive plan to balance the country's rising energy demand with sustainability. Key targets include achieving net-zero emissions in the water and energy sectors by 2050, eliminating clean coal from the energy mix, and tripling the share of renewable energy by 2030. The strategy aims to enhance energy efficiency by 42-45% compared to 2019, increase clean energy capacity to 19.8 GW, and ensure that clean energy constitutes 30% of the total energy mix by 2030 (UAE Government, 2024).

Qatar's National Vision 2030 emphasises sustainable environmental management through various strategic initiatives and targets. Key aspects include efficient resource management, implementing pollution reduction measures, and conserving biodiversity. The plan also focuses on climate change mitigation strategies to ensure a healthy environment for future generations. These initiatives underscore Qatar's broader commitment to sustainable development and environmental stewardship (Qatar GCO, 2024).

As global sustainability initiatives evolve, they increasingly pressure industries to minimise their environmental impact. Data centres, significant energy consumers, are now a focal point for sustainability improvements. This section has reviewed various national and regional sustainability standards, setting the stage to examine the specific growth of data centres and the standards governing their operations. The subsequent section explores the rapid expansion of data centres, their environmental challenges, and the regulatory frameworks designed to enhance their sustainability.

2.3 Data Centres History and Evolution

The drive to achieve net-zero carbon emissions and environmental sustainability is putting increasing pressure on data centres and digital infrastructure. Yet, many people are unaware of how much our everyday economic and social well-being depends on reliable, secure, and efficient data centres and the services they provide.

Data centres house computing and networking equipment for collecting, storing, processing, distributing, or allowing access to large amounts of data. They are essential to IT infrastructure, supporting applications and providing services such as data storage, management, backup and recovery, and networking. As the backbone of the internet and digital services, data centres enable the functionality of almost all sectors of the economy, from financial services and telecommunications to healthcare and retail.

Data centres are facilities that provide the connectivity hubs, power distribution, operational environment, and physical security for the critical equipment needed to support our digital age.

Data centres play a huge role in shaping our modern society. The development of data centres is a witness to the relentless advancement of technology and the growing demand for data processing and storage. From their origins in the 1940s to the sophisticated facilities of today, the growth of data centres has been driven by key technological milestones and evolving needs. A historical perspective not only highlights the innovations that have shaped data centres but also underscores the importance of continued progress in this field.

This section explores these trends and growth, presenting a timeline that details significant milestones and technological advancements in the evolution of data centres. Figure 2.1 presents the growth and evolution of data centres, detailing significant milestones and technological advancements. This timeline illustrates trends that contribute to the increasing energy consumption of data centres and highlights the imperative for sustainable practices.

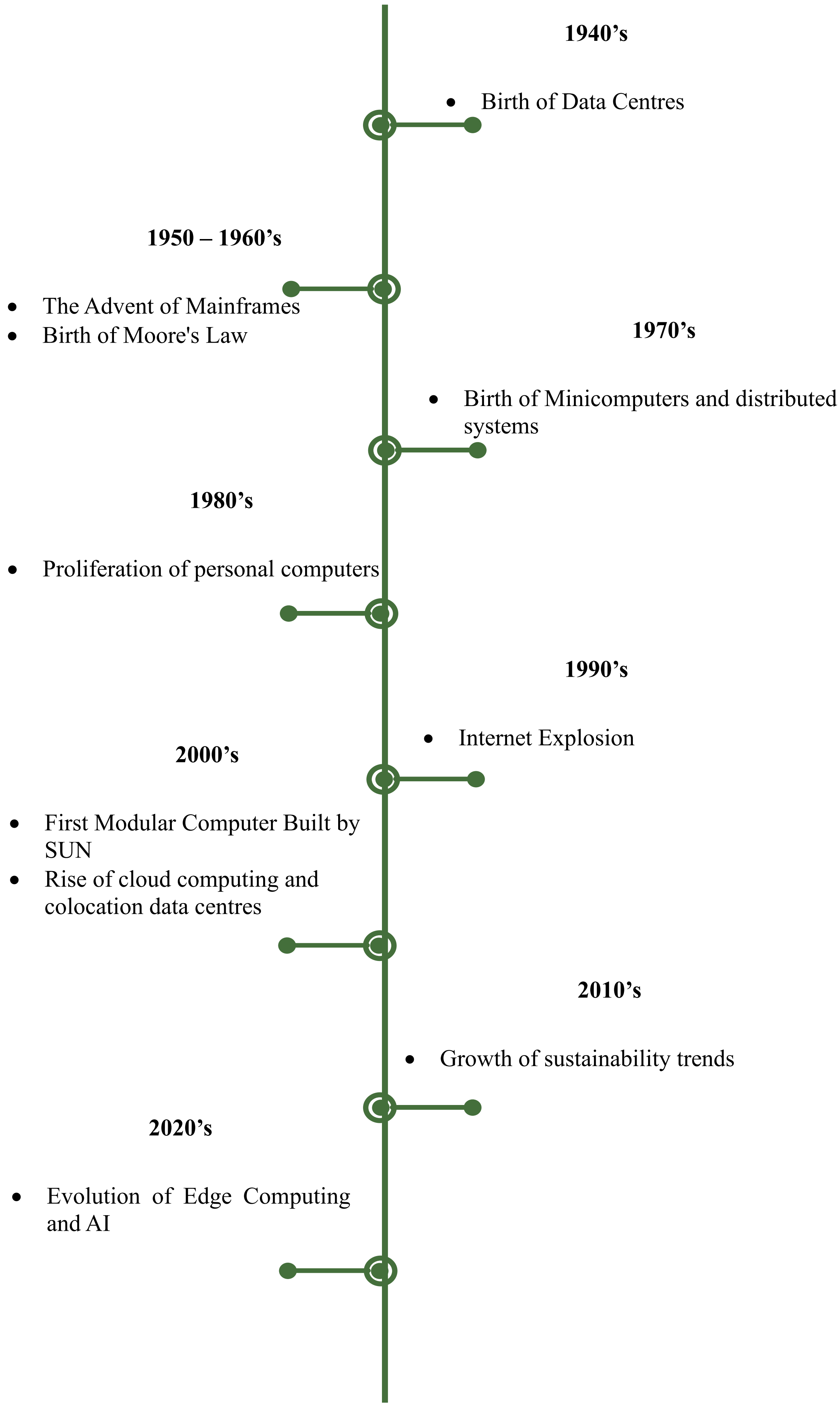

Figure 2.1 Timeline for Data Centre's Evolution and Trends

2.3.1 20th Century Developments of Data Centres

The genesis of data centres can be traced back to the 1940s with the development of the Electronic Numerical Integrator and Computer the world's first programmable computer. Designed to assist the U.S. Army with artillery calculations during World War II, these early facilities were highly secure, often featuring a single secure door and no windows. Significant cooling solutions were necessary to manage the heat generated by electronic components, as overheating was a constant threat, and failures in cooling systems could lead to catastrophic fires (Oakley, 2021; Digital Realty, 2021).

In the 1950s and 1960s, data centres were markedly different from their modern counterparts. At the time, they were known as mainframes rather than data centres. Mainframes were large computers designed to handle significant processing loads and data storage. A notable example from this era is the CDC 6600 from Control Data Corporation, often cited as the first mainframe supercomputer, boasting a processing speed of 40MHz (Digital Realty, 2021).

The transition to transistor-based technology in the 1960s brought rapid advancements in computer speed and storage capacity. This era's technological progress was encapsulated by Moore's Law, formulated in 1965 by Gordon Moore, co-founder of Intel Corporation. Moore's Law described the trend that approximately every 18 months, the number of transistors on a computer chip would double, leading to exponential improvements in computational power and efficiency. This principle heralded an era of rapid technological advancement, enabling the development of smaller, more powerful computing systems (Lawrence National Laboratory , 2017). These improvements facilitated the creation of more sophisticated and efficient data centres.

Moving forward to the 1970s, this decade saw further evolution with the rise of minicomputers (ETHW, 2019) and distributed computing systems, laying the groundwork for more complex and scalable data centre architectures. During this period, significant technological advancements included the development of minicomputers and Ethernet (IEEE Spectrum, 2023). Minicomputers, which were smaller than mainframes, allowed for their widespread use within organisations. The introduction of Ethernet was particularly transformative; it is a system for connecting computers within a local area network (LAN), using protocols to control the passing of information and avoid simultaneous transmission by multiple systems. A LAN refers to a network that connects computers within a limited area such as a residence, school, laboratory, or office building, enabling devices to share resources and information locally (Clark & Reed, 1978). In contrast, a wide-area network (WAN) extends over a large geographic area for the primary purpose of computer networking, allowing LANs from different locations to communicate with each other (Mazhar, 2019). The emergence of Ethernet marked the beginning of both LAN and WAN networking, enabling minicomputers to communicate as clients and servers. This networking capability was pivotal for the future development of data centres, as it facilitated the integration and efficient operation of multiple computing resources within an organisation.

The 1980s saw the introduction of personal computers, such as the IBM PS/1 and PS/2, and the Macintosh. Innovations like MIDI and CD-ROMs also emerged during this period (IEEE, 2021). The widespread adoption of PCs led to a significant increase in demand for networked computing solutions, driving the development of data centres capable of supporting an ever-growing number of networked devices. As the 1990s began, the Internet gained immense popularity, culminating in the creation and rapid expansion of the World Wide Web (WWW), which revolutionised global communication and information sharing (Science Media and Museum, 2020).

By the mid-1990s, the Internet was rapidly gaining popularity, with approximately 45 million users in 1996. This number grew exponentially, reaching 150 million worldwide by 1999, with more than half of these users based in the United States. By the year 2000, the global Internet user base had surged to 407 million (Anderson, 2005). This massive increase in internet usage necessitated more robust data centre infrastructures to handle the escalating web traffic and data storage demands. By the end of the 20th century, data centres had evolved significantly, setting the stage for the transformative advancements that would characterise the early 21st century.

2.3.2 21st Century Developments of Data Centres

As we moved into the 21st century, data centres continued to evolve rapidly. The 2000s were defined by the rise of paradigms such as Cloud Computing, Smart Cities, and the IoT, a shift that revolutionised how data centres operated. Moreover, it is the introduction and rise of modular data centres.

In 2006, Sun Microsystems released the first commercial container data centre product, Project Blackbox, which extended the boundaries of the data centre universe and provided additional options to managers of fast-growing enterprises (SUN Microsystem, 2008; KSTAR, 2020). Moreover, 2006 marked the rise and introduction of cloud computing, with Amazon launching Amazon Web Services (AWS, 2006). This has been followed by other companies introducing cloud computing, leading to the widespread adoption of cloud computing This development allowed businesses to move away from on-premises IT infrastructure, reducing costs and increasing flexibility.

Moving forward to the 2010's era, the vast amounts of data generated by IoT devices required robust data centre infrastructure for storage and processing. This era also brought heightened awareness of the environmental impact of data centres, leading to increased efforts to improve energy efficiency and sustainability. Innovations in cooling technologies (Nadjahi, et al., 2018), renewable energy adoption, and the implementation of energy-efficient hardware became critical to minimising the carbon footprint of data centres (Oro, et al., 2015). In 2011, Facebook launched the Open Compute Project to share specifications for energy-efficient data centres, aiming to deliver a 38% increase in energy efficiency at a 24% lower cost (Open Compute Project, 2011).

This decade also saw the rise of Power Usage Effectiveness (PUE) as a key metric for measuring the energy efficiency of data centres. PUE is calculated by dividing the total amount of energy used by a data centre by the energy used by its IT equipment. A lower

PUE indicates higher efficiency, and efforts to reduce PUE have become central to sustainability initiatives within the industry. However, this KPI is increasingly being recognised as an insufficient proxy for data centre efficiency. This recognition sheds the light on seeing a holistic energy efficiency including the servers and IT equipment.

This era witnessed the introduction of energy-efficient IT and servers, as well as more efficient hardware. For example, the relationship between utilisation and server refresh rates emerged as a critical factor in enhancing energy efficiency. Studies have shown that optimising server refresh cycles and adopting a circular economy approach can significantly improve data centre performance and sustainability. Regularly refreshing servers with newer, more energy-efficient models can reduce overall power consumption and operational costs. Refreshing servers older than five years with newer models can lead to substantial energy savings, as older servers consume a disproportionate amount of energy relative to their computing capacity. Furthermore, the use of refurbished and remanufactured servers has been shown to provide similar reliability and performance as new servers while significantly reducing environmental impact (Bashroush, et al., 2020).

Forwarding to the current decade, the 2020s are marked by the integration of edge computing and AI in data centres. Edge computing brings data processing closer to the source, reducing latency and improving performance for real-time applications such as autonomous vehicles and smart cities (Urblik, et al., 2023). AI and machine learning are increasingly used to optimise data centre operations, predicting maintenance needs, managing energy consumption, and enhancing overall efficiency. Additionally, the rise of AI technologies like ChatGPT and other machine learning models has driven further advancements in data centre infrastructure, ensuring that these facilities can support the computational demands of training and inference tasks associated with AI applications.

The increase in these paradigms and trends in data centres is accompanied by a rise in energy consumption and the number of data centres. The next section presents an overview of the growth of data centres related to energy consumption, the data centres' market, and rack density.

2.4 Data Centres' Growth

Data centres are experiencing the most rapid growth in energy consumption and carbon footprint within the ICT sector. This trend is largely driven by advancements in technologies such as cloud computing and the widespread adoption of Internet services. However, data centres can vary significantly in size and energy consumption, from small server rooms to massive facilities housing thousands of servers. As the demand for digital services grows, so does the energy consumption of data centres.

For instance, in the EU, data centres consumed a substantial 124 TWh of energy in 2018 (Bashroush, 2018). Moreover, it is projected that energy consumption will increase by 28.2% by 2030 compared to 2018 consumption, potentially accounting for about 3.2% of the EU's total electricity demand (EU Commission, 2023d). This significant increase is particularly noticeable in smaller countries. For example, in Ireland, data centres represented approximately 18% of the total electricity consumption in 2022, reflecting the growing energy demands as the digital economy expands. Noting that 82% of the electricity demand from the ICT sector in Ireland was attributed to data centres (SEAi, 2022).

However, energy consumption alone does not provide a complete picture of the impact of data centres. The environmental impact is also influenced by the source of electricity used to power these facilities. In the EU, there is a significant difference in the source of electricity and grid intensity across member states. For example, in China, data centres accounted for 2.71% of the national electricity consumption in 2020 and are expected to account for 4.05% by 2025 (Li, et al., 2023). This figure is particularly concerning given that China relied on fossil fuels for 65% of its electricity in 2023, making it the world's largest emitter of carbon dioxide (EMBER, 2023).

The data centre market is projected to grow at a compound annual growth rate (CAGR) of 9.6% from 2023 to 2030 (Industry ARC, 2024). The adoption of advanced technologies such as AI, Machine Learning, the IoT, Cloud Computing, and Edge Computing creates significant opportunities for the data centre market. A key challenge associated with this growth is the increase in rack density. The rise of AI significantly contributes to this trend. Although specific data on rack density growth is scarce, industry estimates highlight the magnitude of this issue. Companies operating data centres have increased rack densities from 3 kW decade ago to an average of 10 kW per rack currently. However, this remains insufficient for AI and high-performance computing, which require rack densities of up to 100 kW per rack (JLL, 2024). As rack power densities increase, cooling becomes a challenge, prompting the market to explore liquid cooling solutions in the coming years (Mitsubishi, 2023).

With this growth, the term green data centre is becoming increasingly relevant. The global green data centre market was valued at USD 58.77 billion in 2023 and is expected to grow at a CAGR of 19.40% during the forecast period (Polaris Market Research , 2024). However, the definition of a green data centre remains somewhat ambiguous in terms of how it is achieved. A green data centre, is often defined as an environmentally friendly or eco-friendly data centre, is a facility designed to optimise energy efficiency and minimise environmental impact. These centres are built and operated with a focus on sustainability and reducing the carbon footprint associated with data processing and storage. A data centre can be considered green if it is more energy-efficient, located in a country with low grid intensity or has certification from Green Building Certification systems such as LEED and BREEAM. On the other hand, a study on green data centres can be classified based on the governmental framework. For example, in China, 153 green data centres have been established across various provinces and cities, based on the evaluation of technical standards for green data centres (Li, et al., 2023).

With increasing awareness of the significant energy consumption by data centres, governments are implementing policies, frameworks, and regulations to promote greener data centres. The following section will explore the current regulations, policies, and standards for data centres, followed by existing holistic frameworks.

2.5 Global Policies, Standards and Best Practices for Data Centres

As the environmental impact and energy consumption of data centres continue to grow, the role of governmental policies in promoting compliance and motivating efficiency becomes increasingly critical. Governments around the world are implementing a range of regulations, policies, and standards aimed at guiding the data centre industry towards more sustainable and energy-efficient practices. These measures are designed not only to enforce compliance but also to encourage the adoption of greener technologies and practices. This section explores various governments and international bodies that are addressing the challenges posed by data centre energy consumption and environmental impact.

2.5.1 Overview of Some Governmental Global Data Centre Policies

Governments globally are imposing minimum energy performance standards and implementing permitting schemes to ensure data centres operate sustainably. These regulatory frameworks are crucial for mitigating the environmental impact of data centres and enhancing their energy efficiency. These policies have seen an uptake trend over the past decade, accompanied by the introduction of standards for data centres, including PUE and IT efficiency metrics from ISO and EN standards bodies.

Starting with the European region, which is a strong advocate for data centre sustainability, the EU Energy Efficiency Directive (EED) mandates that data centres with an energy demand of 1MW or more must adhere to best practices outlined in the EU Code of Conduct. This directive ensures that data centres employ waste heat recovery whenever technically and economically feasible. The EED, updated in September 2023, places an obligation on Member States to require owners and operators of eligible data centres to make specific information publicly available, except for information protected by trade and business secrets and confidentiality laws. Data centres with a total rated energy input greater than 1MW must utilise waste heat recovery applications unless it is not technically or economically feasible. The directive applies to data centres with a power demand of installed IT equipment of at least 500kW, with exclusions for data centres used exclusively for defence and civil protection purposes. The data collected, which must be published annually, includes details such as the name of the data centre, the owner and operator, the date of operation commencement, location, floor area, installed power, data traffic, data storage and processing amounts, and various performance metrics such as energy consumption, power utilisation, temperature set points, waste heat utilisation, water usage, and use of renewable energy. This reporting will be enforced starting September 2024, playing a significant role in ensuring transparency and facilitating the measurement and enhancement of the environmental impact of data centres (European Union Law, 2023).

In Germany, as part of the Energy Efficiency Act (EnEfG), data centres must introduce energy management or environmental management systems and have these validated or certified if the connected power exceeds one megawatt. Data centres with a non-redundant rated electrical connected load from 300 kilowatts and up must meet energy performance criteria. Larger data centres (≥1MW) and those owned or operated by public bodies (≥200kW) must have certified energy and environmental management systems. The act imposes key metrics and targets; for example, existing data centres must achieve a PUE ≤ 1.5 by July 1, 2027, and a PUE ≤ 1.3 by July 1, 2030. New data centres commencing operations from July 1, 2026, must achieve a PUE ≤ 1.2 and a minimum of 10% reused energy, increasing to 15% by July 1, 2027, and 20% by July 1, 2028. Additionally, from January 1, 2024, 50% of electricity consumed by data centres must come from unsubsidised renewable sources, increasing to 100% by January 1, 2027. Operators are required to establish an energy or environmental management system by July 1, 2025, which includes continuous measurement and improvement of energy efficiency (Federal Ministry for Economic Affairs and Climate , 2024; DLAPiper, 2023).

Other performance policies in Europe also include the ELAN Decree n2019-771 in France and energy savings obligations in the Netherlands, both introduced in 2019. These regulations collectively contribute to a comprehensive framework aimed at reducing the environmental footprint of data centres across Europe.

Moving to Asia Region, several obligations and schemes have been introduced. For instance, China has implemented the Three-Year Action Plan on new data centres, which sets specific development targets aimed at improving energy efficiency and reducing environmental impact. This includes achieving a utilisation rate of more than 60% per new data centre, a total computational power scale exceeding 200 Exa Floating Point Operations Per Second, EFLOPS, and high-performance computing reaching 10%. Additionally, the PUE of new large-scale data centres should be less than 1.3, and in extremely cold areas, it should be below 1.25. These standards are designed to ensure that new data centres in China are more energy-efficient than conventional ones (GIZ, 2022). Minimum performance standards in China are also imposed by the Data Centre Minimum Energy Performance Standards These standards set specific energy efficiency requirements that data centres must meet to reduce overall energy consumption and enhance operational efficiency (SPC, 2024). For instance, it targets three grades for energy efficiency in a data centre with different PUE values of 1.2,1.3, and 1.5 for Grades 1,2 and 3, respectively.

In Japan, the Act on the Rational Use of Energy, also known as the Energy Conservation Act, sets goals for data centres to enhance their energy efficiency. This policy mandates annual reporting and progress towards achieving benchmark targets, including a PUE ratio of 1.5 or lower. The Act aims to reduce the overall energy consumption of data centres, promote the adoption of advanced energy-saving technologies, and ensure continuous improvement in energy performance. By adhering to these regulations, data centres in Japan are encouraged to optimise their operations and contribute to national sustainability goals (METi, 2022).

Furthermore, Singapore has implemented a permitting scheme for data centres, specifically the Pilot Data Centre Call for Application, which requires new data centres to achieve a PUE ≤ 1.3 and comply with the Green Mark certification. This initiative ensures that data centres in Singapore meet stringent energy efficiency standards and contribute to the country's sustainability goals.

These policies for China, Japan, and Singapore have been introduced in 2021 and 2022, reflecting a growing regional commitment to improving the sustainability of data centres and reducing their environmental impact.

On the other hand, in the United States, the Department of Energy (DOE) has established several initiatives and regulations aimed at improving data centre energy efficiency. The 2016 Strategic Sustainability Performance Plan (SSPP) outlines the DOE's approach to enhancing sustainability across its operations, including data centres. The SSPP emphasises the adoption of advanced energy-efficient technologies, the use of renewable energy sources, and the implementation of best practices for energy management. Key objectives include reducing energy intensity, increasing the use of renewable energy, and improving overall sustainability in data centre operations (U.S DOE, 2016).

The Data Centre Optimisation Initiative (DCOI), managed by the Federal Energy Management Program (FEMP), sets performance metrics and targets for federal data centres. Key components of DCOI include, consolidation of data centres, reducing PUE, Encouraging the use of advanced energy-efficient technologies, such as efficient cooling systems and energy-efficient servers (U.S DOE, 2021).

Finally, regulations are also taking shape in the Middle East and Africa (MEA) region. For example, Saudi Arabia has introduced new data centre services regulations that came into force in 2023. These regulations set specific operational and compliance standards aimed at ensuring data centres operate efficiently and sustainably (W.media, 2024).

Next, an overview of the data centre best practices is presented.

2.5.2 Data Centre's Best Practices

To achieve benchmarks and minimum energy performance, adhering to best practices and specific procurement guidelines is essential. In terms of best practices, the EU Code of Conduct for Data Centres stands out as one of the earliest initiatives to introduce comprehensive guidelines for improving energy efficiency in data centres. This voluntary initiative, developed by the European Commission, aims to reduce the environmental impact of data centres while maintaining operational efficiency. It includes over 100 best practices covering various aspects, such as optimising cooling systems, implementing energy-efficient IT equipment, monitoring and managing energy consumption, and utilising renewable energy sources where possible. Introduced in 2008, the Code of Conduct is updated annually to incorporate new features and practices for data centres.

The Code of Conduct is associated with other policies like the EU Corporate Sustainability Reporting Directive (CSRD) and the EU Taxonomy, which further reinforce the commitment to sustainability and transparency. Globally, similar schemes provide guidelines for energy efficiency and sustainability in data centres. For instance, China's Green Data Centre Standards set rigorous energy performance benchmarks and encourage the adoption of renewable energy sources.

2.5.3 Sustainable Purchases within Data Centres

Following the discussion on various policies and best practices that ensure the sustainability and efficiency of data centres, it is important to recognise how these purchasing criteria are inherently connected to best practices and standards. These procurement guidelines help enforce the adoption of energy-efficient technologies and practices, thereby promoting sustainability and operational efficiency.

Procurement and purchasing policies play an essential role in ensuring the operational efficiency and sustainability of data centres. These policies set criteria for purchasing energy-efficient technologies and services, promoting best practices and reducing the environmental impact of data centres.

One example is the EU Green Public Procurement (GPP) initiative, which includes guidelines for purchasing server rooms, data centres, and cloud services. Although voluntary, these guidelines are designed to help public authorities buy goods and services and work with a reduced environmental impact. The GPP criteria cover various energy-related technical specifications, including server active state efficiency, ICT operating range for temperature and humidity, environmental control facilities complying with standard EN 50600, server idle state power, and the renewable energy factor. These guidelines ensure that data centres operate efficiently and sustainably (EU Commission, 2023e).

Similarly, Ireland's GPP provides guidelines for sustainable public procurement that include data centres within their scope. These guidelines help ensure that procurement processes contribute to environmental sustainability by encouraging the purchase of energy-efficient technologies and services. These guidelines align very similarly with the EU GPP (Government of Ireland, 2021).

In the Netherlands, Sustainable Public Procurement (SPP) guidance targets networks, telephone services, and telephone equipment, including data centres. These guidelines promote the procurement of energy-efficient and environmentally friendly technologies, ensuring that public procurement aligns with sustainability goals. It also tackles social aspects.

The Energy Star program, managed by the U.S. Environmental Protection Agency (EPA), sets energy efficiency standards for various products, including servers. Energy Star-certified servers must meet strict criteria for energy efficiency, both in active and idle states. This certification helps organisations identify and purchase energy-efficient servers, thereby reducing energy consumption and operational costs.

Purchasing requirements and guidelines are crucial for ensuring the operational efficiency and sustainability of data centres. By adhering to these guidelines, organisations can reduce energy consumption through the procurement of energy-efficient technologies, lower operational costs by minimising energy use and improving efficiency and reduce the carbon footprint and overall environmental impact of data centres. Moreover, these policies ensure compliance with national and international sustainability standards.

In conclusion, procurement and purchasing policies are essential tools for promoting sustainability and operational efficiency in data centres. Initiatives like the EU GPP, Ireland's GPP, the Netherlands' SPP, and the Energy Star program provide valuable guidelines that help organisations make informed purchasing decisions that support their sustainability goals.

Next subsection provide an overview of available standards and metrics in data centres.

2.5.4 Widely Adopted Standards and Metrics for Data Centres

This subsection introduces some of the key standards and metrics that are widely adopted on a voluntary basis or recognised and referenced by policies and legislation. Best practices frequently reference these standards to provide clear guidelines and benchmarks. Among these standards, the globally adopted ones are introduced by the International Organization for Standardization (ISO)[3].

ISO standards are developed by ISO, an independent, non-governmental international organisation with a membership of 171 national standards bodies. On the other hand, EN standards, or European Norms[4], are developed by the European Committee for Standardization (CEN) and are applicable within the European Union. Often, EN standards are developed based on existing ISO standards to ensure compatibility and global coherence. This process involves the adoption of ISO standards within the European context, sometimes with modifications to address specific regional requirements.

These standards bodies offer comprehensive guidelines for the design and operation of data centres. For example, operational management aspects, such as power distribution and security systems, are covered within the ISO 22237 series and are mapped with the EN 50600-1, EN 50600-2, and EN 50600-3 series (ISO, 2021; BSI, 2024).

Focusing on environmental sustainability standards, ISO and EN offer a few key performance indicators (KPIs) that play a crucial role in implementing policies and best practices, as well as in the reporting mandated by directives such as the EED. These KPIs are often provided by the ISO 30134 series, which is mapped by the EN 50600-4 series, as shown in Table 2.1.

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[3] ISO. (2023). *About ISO*. Retrieved from https://www.iso.org
[4] CEN-CENELEC. (2023). *About European Standards (EN)*. Retrieved from https://www.cencenelec.eu

Key performance indicators Offered by ISO	Key performance indicators offered by EN
ISO/IEC 30134-1:2016 Information technology — Data centres — Key performance indicators — Part 1: Overview and general requirements	EN 50600-4-1 Information technology. Data centre facilities and infrastructures. Overview of and general requirements for key performance indicators
ISO/IEC 30134-2 Information technology — Data centres — Key performance indicators — Part 2: Power usage effectiveness (PUE)	EN 50600-4-2 Information technology. Data centre facilities and infrastructures. Power Usage Effectiveness
ISO/IEC 30134-3: Information Technology - Data Centres - Key Performance Indicators Part 3: Renewable Energy Factor (REF)	EN 50600-3 Information technology. Data centre facilities and infrastructures. Renewable Energy Factor
ISO/IEC 30134-4:2017 Information technology — Data centres — Key performance indicators — Part 4: IT Equipment Energy Efficiency for servers (ITEEsv)	N/A
ISO/IEC 30134-5:2017 Information technology — Data centres — Key performance indicators — Part 5: IT	N/A

Equipment Utilization for servers (ITEUsv)	
ISO/IEC 30134-6: Information Technology - Data Centres Key Performance Indicators – Part 6: Energy Reuse Factor (ERF)	EN 50600 4-6 Information technology. Data centre facilities and infrastructures. Energy Reuse Factor
ISO/IEC 30134-7: Information Technology - Data Centres Key Performance Indicators – Part 7: Cooling Efficiency Ratio (CER)	EN 50600 4-7 Information technology. Data centre facilities and infrastructures. Cooling Efficiency Ratio
ISO/IEC 30134-8: Information Technology - Data Centres Key Performance Indicators – Part 8: Carbon Usage Effectiveness (CUE)	EN 50600-4-8 Information technology. Data centre facilities and infrastructures. Carbon usage effectiveness
ISO/IEC 30134-9: Information Technology - Data Centres Key Performance Indicators – Part 9: Water Usage Effectiveness (WUE)	EN 50600 4-9 Information technology. Data centre facilities and infrastructures. Water Usage Effectiveness

Table 2.1 Mapping of ISO 30134 Series with EN 50600 Series for Data Centre Sustainability

Beyond the ISO 30134 series, several other standards address or focus on environmental sustainability and energy management within data centres. These standards are not always complementary between the two standards bodies include:

- ISO/IEC 21836:2020 Information technology — Data centres — Server energy effectiveness metric
- ISO/IEC 23544:2021 Information Technology — Data centres — Application Platform Energy Effectiveness (APEE)
- ISO/IEC 19395:2015 Information technology — Sustainability for and by information technology — Smart data centre resource monitoring and control
- ISO/IEC TR 20913:2016 Information technology — Data centres — Guidelines on holistic investigation methodology for data centre key performance indicators
- ISO/IEC TR 21897:2022 Information technology — Data centres — Impact of the ISO 52000 series on the energy performance of buildings
- ISO/IEC TR 23050:2019 Information technology — Data centres — Impact on data centre resource metrics of electrical energy storage and export
- ISO/IEC TR 30133:2023 Information technology — Data centres — Practices for resource-efficient data centres
- ISO/IEC 24091:2019 Information technology — Power efficiency measurement specification for data centre storage
- CLC/TR 50600-99-1:2021 Information technology - Data centre facilities and infrastructures- Part 99-1: Recommended practices for resource management

- CLC/TR 50600-99-2:2021 Information technology - Data centre facilities and infrastructures - Part 99-2: Recommended practices for environmental sustainability

- CLC/TS 50600-5-1 Information technology - Data centre facilities and infrastructures - Part 5-1: Maturity Model for Energy Management and Environmental Sustainability

In addition to these key standards, other relevant standards, such as ISO 50001 for energy management systems and ISO 14001 for environmental management, also play significant roles. Furthermore, other nationally adopted standards have been developed by organisations such as American National Standards Institute (ANSI) [5], the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) [6], and the International Telecommunication Union (ITU) [7].

ITU Standards

- ITU-T L.1300: Best practices for green data centres.

- ITU-T L.1301: Minimum data set and communication interface requirements for data centre energy management.

- ITU-T L.1302: Assessment of energy efficiency on infrastructure in data centres and telecom centres.

- ITU-T L.1320: Energy efficiency metrics and measurement for power and cooling equipment for telecommunications and data centres.

[5] ANSI. (2023). *About ANSI*. Retrieved from https://www.ansi.org
[6] ASHRAE. (2023). *About ASHRAE*. Retrieved from https://www.ashrae.org
[7] ITU. (2023). *About ITU*. Retrieved from https://www.itu.int

ANSI Standards

- ANSI/TIA 942: Telecommunications Infrastructure Standard for Data Centres.

ETSI Standards

- ETSI TS 105 174-2: Access, Terminals, Transmission, and Multiplexing (ATTM); Broadband Deployment - Energy Efficiency and Key Performance Indicators; Part 2: Network sites; Sub-part 2: Data centres.
- ETSI EN 303 470: Information technology - Data Centres - Server Energy Effectiveness Metric.

Collectively, these standards create a robust framework that supports data centres in their quest for sustainability, ensuring they meet high performance and environmental benchmarks on both national and international levels.

Next section explores holistic certification assessing data centres.

2.6 Holistic Certification for Data Centres

In the realm of holistic sustainability assessment, BREEAM (Building Research Establishment Environmental Assessment Method) and LEED (Leadership in Energy and Environmental Design) stand out as comprehensive certification systems that cover a wide range of impacts from procurement to construction. These systems are designed to capture a broad spectrum of sustainability factors, including location, construction practices, energy and water usage, indoor environmental quality, and materials. Both certifications include specific criteria for data centres, yet they often lack clear distinctions in credits compared to other buildings. This general approach can be a drawback, as data centres have unique operational demands that are not always adequately addressed by generic building standards.

BREEAM recognises and recommends adherence to the EU Code of Conduct for Data Centres. Despite this acknowledgement, the industry still lacks full trust in both BREEAM and LEED certifications (BRE, 2019). One significant challenge is the lack of specific distinctions in their credits for data centres compared to other building types. This gap can result in data centres not receiving adequate savings from the certification credits or gaining the right reflectance. However, the incentives to achieve these certifications are growing, driven by the increasing demand for sustainability and the emphasis on ESG reporting. Financial institutions such as Abu Dhabi Islamic Bank (ADIB, 2023) and Danske Bank (Danske, 2022) require minimum certification levels, like LEED Gold or BREEAM Excellent, for funding eligibility. This serves as a significant incentive for data centres to pursue these certifications, ensuring they meet high standards of sustainability and can access necessary funding for their projects.

In addition to LEED and BREEAM, other sustainability certification schemes such as the Certified Energy Efficient Datacentre Award (CEEDA) (DCD, 2024) and the Data

Centre Energy Efficiency Program (DEEP) (DEEP, 2024) have been developed specifically for data centres. CEEDA, for example, focuses on energy efficiency and the implementation of best practices in the design and operation of data centres. DEEP similarly emphasizes energy efficiency and the reduction of carbon footprints in data centre operations. However, while these certifications encapsulate key best practices from frameworks like LEED and BREEAM, they are not as comprehensive in addressing the full spectrum of data centre design and construction. CEEDA and DEEP primarily concentrate on operational energy efficiency, which may result in a narrower focus that overlooks other critical aspects such as the environmental impact of building materials, site selection, and long-term sustainability strategies. This limitation could lead to challenges in achieving holistic sustainability goals, as it may not fully capture the broader environmental impacts that more comprehensive certifications like LEED and BREEAM aim to address.

Supporting this view, the literature calls for the development of specialized sustainability assessment frameworks that are better aligned with the operational realities of data centres (Cai & Gou, 2023). It is noted that the current systems, while comprehensive for general building types, do not adequately reflect the unique environmental challenges posed by data centres, particularly in terms of high energy consumption and cooling requirements. To address these gaps, the authors propose rethinking the weightings and criteria used in existing rating systems to ensure they capture the full spectrum of sustainability impacts specific to data centres.

Despite the widespread use of both certifications, LEED is more globally adopted. LEED’s broader reach is evidenced by its extensive use across various regions, outstripping BREEAM, even within Europe. Moreover, hyperscale data centres operated by companies like Meta and Microsoft emphasise LEED certification in their sustainability reports (Meta, 2024; Microsoft, 2024). These reports highlight the specific measures taken to achieve LEED certification more prominently than BREEAM, further illustrating LEED's widespread acceptance and influence in the industry.

While both BREEAM and LEED are critical in driving sustainable practices, there is a notable gap in research regarding the quantifiable benefits and savings these certifications offer specifically for data centres. Literature supports that LEED is more frequently achieved by data centres due to its broader adoption and flexibility. However, the framework still contains gaps that fail to fully address the unique sustainability challenges posed by these facilities (Cai & Gou, 2023; Moud, et al., 2020).

Current studies often do not fully quantify the potential savings that LEED certified data centres can achieve. Moreover, the effectiveness of higher certification levels is not adequately explored. This lack of detailed analysis hinders a comprehensive understanding of how these certifications can reflect data centre sustainability performance.

The next section explores LEED certification and its specific components.

2.7 LEED Certification

LEED is an internationally recognised green building certification system developed by the U.S. Green Building Council (USGBC). It provides a framework for healthy, efficient, and sustainable building design, construction, and operation. The latest version, LEED v4, offers customised benchmarks for various building types, including new construction, core and shell buildings, schools, retail, warehouses and distribution centres, hospitality, healthcare, and data centres.

There are several different LEED rating systems, each designed for a specific type of property type or project. This research focuses on LEED Building Design and Construction (BD+C), which is designed for new construction projects or major renovations. LEED provides a framework drafted by professionals for implementing practical and measurable environmental solutions. The first LEED criteria were launched in 2007 as LEED v3, which was later updated to LEED v4 to include data centre criteria. LEED v4.1, which slightly differs from LEED v4, has also been introduced. However, most certifications are currently under LEED v4. The LEED BD+C is more frequently achieved in the data centre industry, as LEED Operation and Maintenance (O+M) is less commonly pursued (USGBC, 2024b) due to the presence of more tailored best practices for the data centre's operational phase. Moreover, this research focuses on the holistic approach offered by BD+C.

The criteria are built up of mandatory (prerequisites) and optional practices (credits) that reward a project. These credits and prerequisites fall under six main credit categories and additional bonus credits:

Location & Transportation (LT)

This category encourages development in sustainable locations to reduce environmental impacts associated with transportation. Credits include proximity to public transportation, access to quality transit, and reducing the parking footprint.

- LT Credit: LEED for Neighbourhood Development Location: 16 points
- LT Credit: Sensitive Land Protection: 1 point
- LT Credit: High Priority Site: 2 points
- LT Credit: Surrounding Density and Diverse Uses: 5 points
- LT Credit: Access to Quality Transit: 5 points
- LT Credit: Bicycle Facilities: 1 point
- LT Credit: Reduced Parking Footprint: 1 point
- LT Credit: Green Vehicles: 1 point

Sustainable Sites (SS)

The category promotes strategies that minimise the impact on ecosystems and water resources. Credits cover site assessment, site development, rainwater management, and heat island reduction.

- SS Prerequisite: Construction Activity Pollution Prevention
- SS Credit: Site Assessment: 1 point
- SS Credit: Site Development - Protect or Restore Habitat: 2 points
- SS Credit: Open Space: 1 point
- SS Credit: Rainwater Management: 3 points
- SS Credit: Heat Island Reduction: 2 points
- SS Credit: Light Pollution Reduction: 1 point

Water Efficiency (WE)

It aims to reduce water consumption. Credits focus on reductions in indoor water use, outdoor water use, and water metering.

- WE Prerequisite: Outdoor Water Use Reduction
- WE Prerequisite: Indoor Water Use Reduction
- WE Prerequisite: Building-Level Water Metering
- WE Credit: Outdoor Water Use Reduction: 2 points
- WE Credit: Indoor Water Use Reduction: 6 points
- WE Credit: Cooling Tower Water Use: 2 points
- WE Credit: Water Metering: 1 point

Energy & Atmosphere (EA)

It focuses on optimising energy performance and using renewable energy. Includes prerequisites and credits for commissioning, energy performance, and renewable energy production.

- EA Prerequisite: Fundamental Commissioning and Verification
- EA Prerequisite: Minimum Energy Performance
- EA Prerequisite: Building-Level Energy Metering
- EA Prerequisite: Fundamental Refrigerant Management
- EA Credit: Enhanced Commissioning: 6 points
- EA Credit: Optimise Energy Performance: 18 points
- EA Credit: Advanced Energy Metering: 1 point
- EA Credit: Demand Response: 2 points
- EA Credit: Renewable Energy Production: 3 points
- EA Credit: Enhanced Refrigerant Management: 1 point
- EA Credit: Green Power and Carbon Offsets: 2 points

This category differs slightly in LEED v4.1, where the Green Power and Renewable Energy Production credits are merged.

Materials & Resources (MR)

The category encourages the use of sustainable building materials and the reduction of waste. Credits include building life-cycle impact reduction, environmentally preferable products, and waste management.

- MR Prerequisite: Storage and Collection of Recyclables
- MR Prerequisite: Construction and Demolition Waste Management Planning
- MR Credit: Building Life-Cycle Impact Reduction: 5 points
- MR Credit: Building Product Disclosure and Optimisation - Environmental Product Declarations: 2 points
- MR Credit: Building Product Disclosure and Optimisation - Sourcing of Raw Materials: 2 points
- MR Credit: Building Product Disclosure and Optimisation - Material Ingredients: 2 points
- MR Credit: Construction and Demolition Waste Management: 2 points

Indoor Environmental Quality (IEQ)

This enhances indoor air quality and occupant comfort. Credits cover ventilation, thermal comfort, lighting quality, and acoustic performance.

- IEQ Prerequisite: Minimum Indoor Air Quality Performance
- IEQ Prerequisite: Environmental Tobacco Smoke Control
- IEQ Credit: Enhanced Indoor Air Quality Strategies: 2 points
- IEQ Credit: Low-Emitting Materials: 3 points
- IEQ Credit: Construction Indoor Air Quality Management Plan: 1 point
- IEQ Credit: Indoor Air Quality Assessment: 2 points

- IEQ Credit: Thermal Comfort: 1 point
- IEQ Credit: Interior Lighting: 2 points
- IEQ Credit: Daylight: 3 points
- IEQ Credit: Quality Views: 1 point
- IEQ Credit: Acoustic Performance: 1 point

Innovation (IN)

This additional category rewards innovative strategies and exemplary performance beyond the LEED requirements. Credits include innovation, pilot credits, and LEED Accredited Professional (AP).

- IN Credit: Innovation: 5 points
- IN Credit: LEED Accredited Professional: 1 point

Regional Priority (RP)

Addresses geographically specific environmental priorities. Credits vary by location and are determined by USGBC regional chapters.

- RP Credit: Regional Priority: 4 points

Integrative Process (IP)

Encourages early collaboration among project team members to achieve high-performance, cost-effective outcomes.

- Integrative Process Credit: 1 point

Each category includes prerequisites that must be met and credits that contribute to the overall score. The certification levels are Certified, Silver, Gold, and Platinum, based on the total points achieved. The total points that can be achieved is 100, plus an additional ten bonus points. The certification levels are:

- Certified: 40-49 points

- Silver: 50-59 points
- Gold: 60-79 points
- Platinum: 80+ points

A Sample scorecard is shown in Figure 2.2.

Figure 2.2 LEED Scorecard Sample

2.8 LEED Certification for Data Centres

Data centres are unique building types with specific operational demands, particularly in energy and cooling. LEED v4 includes provisions for data centres, though it primarily focuses on broader sustainability measures that may not fully address their unique attributes. More than 90% of the credits are shared with other building criteria (Moud, et al., 2020).

Recognised Categories and Credits for Data Centres:

- **Energy & Atmosphere (EA)**
  - Prerequisite: Fundamental Commissioning & Verification
  - Prerequisite: Minimum Energy Performance
  - Credit: Enhanced Commissioning (6 points)
  - Credit: Optimise Energy Performance (18 points)
- **Indoor Environmental Quality (IEQ)**
  - Credit: Enhanced Indoor Air Quality Strategies (2 points)
  - Credit: Thermal Comfort (1 point)

The following section provides an overview on emissions classifications.

2.9 Direct and Indirect Emissions

When addressing environmental sustainability, it is imperative to integrate a detailed understanding of greenhouse gas (GHG) emissions. Data centres, as significant consumers of energy, contribute substantially to GHG emissions. GHG emissions are categorised into Scope 1, Scope 2, and Scope 3, each reflecting different aspects of emission sources and impacts, often classified as direct and indirect emissions (GHG Protocol, 2004).

Scope 1: Direct Emissions

Scope 1 emissions are direct GHG emissions from sources that are owned or controlled by the organisation. These include emissions from fuel combustion in company-owned vehicles and facilities, as well as emissions from refrigeration and air conditioning systems.

In a data centre, Scope 1 primarily arises from the use of backup generators and refrigerants. Backup generators, typically diesel-powered, are critical for ensuring uninterrupted operation during power outages. However, they emit substantial amounts of CO_2 and other pollutants when operated. Additionally, the use of refrigerants in cooling systems can lead to fugitive emissions if these substances leak. Refrigerants often have a high Global Warming Potential (GWP), making their management crucial for minimising Scope 1 emissions.

Scope 2: Indirect Emissions from Energy

Scope 2 emissions are indirect GHG emissions from the consumption of purchased electricity, heat, steam, or cooling. These emissions occur at the facility where the energy is generated but are accounted for in the organisation's GHG inventory because of their use of the energy.

For data centres, Scope 2 emissions are significant due to their substantial electricity consumption to power servers, networking equipment, and cooling systems. The source of the electricity (renewable vs. fossil fuels) greatly influences the magnitude of these emissions.

Scope 3: Other Indirect Emissions

Scope 3 emissions are all other indirect emissions that occur in the value chain of the reporting company, including both upstream and downstream emissions. These can result from a variety of activities such as the production and transportation of purchased goods and services, waste disposal, business travel, and employee commuting.

In the context of data centres, Scope 3 emissions can include emissions from the production and transportation of IT hardware, the construction and maintenance of the facility, employee travel, and the eventual disposal of e-waste. The lifecycle of a server or any piece of data centre equipment begins with the mining of minerals, the production of components, and the assembly of the final product. Each stage of this supply chain produces emissions, and when aggregated, they form a significant portion of the indirect emissions associated with data centre operations.

In the context of LEED certification, GHG emissions are addressed through various strategies and credits. Scope 1 emissions are managed by enhancing refrigerant practices and promoting the use of low Global Warming Potential (GWP) refrigerants, as well as strategies to reduce cooling loads. Scope 2 emissions are primarily addressed within the Energy & Atmosphere (EA) category, which focuses on minimising energy use and encouraging the adoption of green power. Scope 3 emissions, while less comprehensively covered, are acknowledged through credits related to sustainable construction materials and the reduction of transportation emissions. This integration within LEED aims to reduce the overall carbon footprint of data centres and enhance their sustainability performance.

Next section provide a summary for the chapter.

2.10 Conclusion

This chapter provides a comprehensive review of the evolving landscape of environmental sustainability, particularly within the context of data centres. It explores several global regulations, policies, and best practices aimed at reducing carbon emissions, including those directly targeting data centres and others with indirect implications for the sector. Policies such as the Paris Agreement and the European Green Deal push industries toward net-zero carbon emissions by 2050, with a growing focus on sectors like data centres due to their high energy consumption and environmental impact.

The chapter traces the history and rapid growth of data centres, highlighting the increasing reliance on digital technologies, which drives up demand for data storage and processing capabilities. As a result, data centres have become significant contributors to global energy consumption, necessitating more stringent sustainability standards.

A review of existing sustainability certifications, such as LEED and BREEAM, reveals that while they are widely adopted, they often fall short of addressing the unique environmental challenges posed by data centres. These frameworks tend to focus more on traditional building aspects and less on the operational specifics of data centres, such as IT load and cooling efficiency. As a result, they often fail to fully capture the environmental performance of these facilities.

The chapter concludes by identifying a critical gap in the current literature and sustainability frameworks. There is a clear need for a more tailored and comprehensive approach to sustainability certification for data centres, one that better reflects their operational realities and environmental impacts. This review sets the stage for the following chapters, which introduce and develop a new scoring model aimed at addressing these gaps and improving the sustainability assessment of data centres.

The next chapter presents the methodology used in this research.

Chapter 3. Research Methodology

3.1 Introduction

This research aims to study the effectiveness of LEED certification and address its gaps. To achieve this aim and answer the research questions, this chapter outlines the methodology used in the research. It provides a comprehensive overview of the research data collection methods and data analysis techniques employed in this study. Table 3.1 offers an overview of the methodology used.

High-Level Methodology	Detailed Overview
Literature Review	Data Centre and Sustainability background
	Evolution of Environmental Sustainability
	Data Centre Growth
	Environmental Sustainability Standards and Regulations Related to Data Centres
	LEED Certification Overview
Data Collection	LEED Certified Data Centres from USGBC
	Variables and Parameters Used in Environmental Model
Data Analysis	Meta-Analysis and Statistical Analysis
	Credits Individual Analysis
Environmental Model	Mathematical Calculations for Environmental Credits' Actual Savings
	Case Studies Application
	Effectiveness Analysis

	Effectiveness Verification
Addressing Gaps	Proposal of New Scoring Schemes
	Credits Requirements Gaps and adjustments Proposal
Certification Concluding Analysis	Conducting a SWOT analysis to summarise the strengths, weaknesses, opportunities, and threats of LEED certification for data centres.
Verification for Proposed New Scoring Scheme	Comparing new scores to actual savings and studying their effectiveness
Conclusion	Concluding on results and proposing future research

Table 3.1 Overview of Methodology Used in Research

The following sections of this chapter describe the methods and data collection techniques used throughout the research.

3.2 Literature Review

The literature review, detailed in Chapter 2, provides a foundational understanding of data centres, their evolution, current state, and global growth. Additionally, it examines the development of environmental sustainability and the evolution of green practices and ambitions worldwide. The literature review emphasises the importance of applying best practices tailored to data centres and explores existing standards, regulations, and certifications.

The purpose of this literature review is to highlight the significance and novelty of this research by identifying gaps in the current literature. The main sources of information include peer-reviewed articles from academic journals, academic publications, books, and online resources from governmental and non-governmental organisations. Conferences that reflect stakeholders' needs and data centre operations were also attended. These sources were crucial in addressing the current gaps and needs in data centre sustainability.

To address the gaps identified in the literature and answer the research questions, data is collected first. The next section details the data collection methods.

3.3 Data Collection

Data centres are the focus of this research, specifically those certified with LEED BD+C Data Centres v4.0, v4.1. Data for this study are collected from the USGBC website (USGBC, 2024a), with all data extracted as of February 2024. This dataset includes information on newly built data centres, such as the data centre name, country, certification level, date of certification, total scores, and credit individual scores. In total, 84 certified data centre projects are studied. The data of the 84 data centres are presented in Appendix A: Certified LEED Data Centres.

To support the calculations and mathematical analyses, additional desk research is conducted to extract variable values. These variables include grid intensity for various countries, average emissions per passenger car, average daily distance travelled by staff in different countries, and average rail emissions. Furthermore, specific variables related to practices and credits are gathered, including percentage emissions savings associated with practices, such as commissioning credits and energy metering.

The main sources of information are journal papers, academic research, and governmental publications. To ensure validity, the information is cross-checked through multiple freely accessible sources, industrial reports, and real-life case studies. This comprehensive data collection approach ensures a robust foundation for analysing the effectiveness of LEED certification and addressing gaps in the current framework.

After collecting data, the next section explores the analysis conducted.

3.4 Data Analysis

The data analysis process is divided into two main parts: meta-analysis and credit scoring statistical analysis. This initial analysis addresses two key research questions:

R.Q.1 - What are data centres' attainment patterns and growth trends approaching LEED certification, considering geographical regions, year of certification, and certification levels?

R.Q.2 - How do data centres perform in achieving LEED credits, and what factors influence the attainability of these credits?

These questions are explored to reveal critical insights into the certification landscape and performance metrics of data centres under the LEED framework.

3.4.1 Meta-Analysis

In the first stage, data centres certified with LEED BD+C Data Centres are grouped based on geographical regions, year of certification, and certification levels. The purpose is to analyse trends, regional influences, and the impact of regulations on certification outcomes. This comprehensive approach helps identify broader patterns and influences within the dataset.

Each region's regulatory environment, industrial practices, and governmental policies significantly impact LEED certification outcomes. For instance, countries with more stringent environmental regulations might influence higher certification levels and more rigorous implementation of green practices compared to regions with less stringent policies.

By examining the data through the lens of these regional influences, the analysis can pinpoint how local policies and industrial standards drive sustainability efforts in data centres. Furthermore, comparing trends across different certification years highlights how changes in LEED standards or external environmental policies impact the adoption of specific credits over time.

Overall, this meta-analysis integrates insights from literature, governmental reports, and industry data to understand how various factors influence LEED certification outcomes in different regions. This thorough examination helps contextualise data centres' performance within their specific regulatory and industrial environments.

3.4.2 Credit Statistical Analysis

Following the meta-analysis, a detailed statistical analysis of the USGBC scorecard dataset was conducted. Statistical formulas were applied to evaluate the credits attained by data centres under LEED. To begin, we employed statistical techniques to analyse the scores of various credits achieved by data centres.

Descriptive statistics and mathematical equations are used to create candlestick plots, illustrating the most and least attained credits. These plots help visualise the scores' distribution and identify credit attainment trends.

The analysis calculated the upper and lower thresholds for data centre performance and the attainment of individual credits. Statistical parameters are then presented in a candlestick chart for analysis.

After analysing the credit attainment trends, the average attainment for each LEED credit is quantitatively analysed to determine which credits are most frequently achieved. This helps understand the relative popularity and difficulty of different credits within the data centre industry.

The results from these analyses demonstrate each LEED credit's attainment levels and frequency across the data centre industry. Factors influencing the attainability of LEED credits include the difficulty level, resource availability, and prioritisation among data centres.

The next section details the environmental modelling.

3.5 Environmental Impact Modelling

After assessing the approach of data centres towards LEED certification, a thorough examination of the criteria in the LEED framework was carried out to pinpoint any gaps and areas for enhancement. The model will address the following research questions:

R.Q.3- What are the maximum savings potential of environmental credits in LEED?

R.Q.4- Are these savings reflected correctly in the current LEED scoring system?

To facilitate this, an environmental impact model is developed to calculate the environmental impact reduction opportunities relating to the various criteria based on the unique characteristics of a given data centre. The model is applied on 5 different case studies presented in Chapter 5. Following the calculations, a comparison is made to assess how LEED reflect these credits.

Key factors affecting environmental impact include data centre type, IT power, geographical location, grid intensity, renewable energy sources, and transportation infrastructure.

The selected credits are chosen for their direct relation to CO_2 emissions and their significant impact on overall environmental performance. The credits included in this analysis are:

- Access to Quality Transit: Encourages multimodal transportation, reducing reliance on personal vehicles and decreasing CO_2 emissions.
- Bicycle Facilities: Promotes cycling as an alternative to driving, cutting down on vehicle emissions.
- Electric Vehicles: Supports the shift from fossil fuel-powered vehicles to electric vehicles, lowering greenhouse gas emissions.

- Heat Island Reduction: Aims to reduce heat absorption by buildings, decreasing cooling loads and associated emissions.
- Enhanced Commissioning: Ensures that building systems are designed, installed, and calibrated for optimal performance, leading to energy savings and reduced emissions.
- Optimise Energy Performance: Focuses on improving overall energy efficiency, directly impacting CO_2 emissions from energy use.
- Advanced Energy Metering: Supports detailed tracking of energy use to identify any inefficiencies and identifying energy wastage that leads to energy-saving opportunities.
- Renewable Energy: Promotes using renewable energy sources, which are crucial for reducing emissions.
- Building Life-Cycle Impact Reduction: Encourages materials and construction methods that reduce the overall environmental impact, including CO_2 emissions.
- Construction and Demolition Waste Management: Aims to divert waste from landfills through 3R's methods. These methods include, recycle, reduce, and reuse. Thereby reducing the environmental footprint of construction activities.

Following our calculation, LEED certification modifications are suggested to address the gaps.

3.6 Addressing Gaps

After exploring the gaps in LEED certification for Data Centres, gaps are addressed to answer these two Questions:

R.Q.5- How can the LEED scoring scheme be amended to reflect better the actual environmental savings and contributions of data centres?

R.Q.6- How can the LEED credits be adjusted to consider data centres differently than other buildings, better reflecting their unique environmental impacts and operational characteristics?

Our analysis identifies gaps in the LEED scoring scheme to reflect data centre savings and environmental contributions better. These gaps are addressed by proposing new flexible scoring schemes to better reflect actual opportunities. Moreover, environmental credits were explored and classified according to their relative efficacy to better communicate this to stakeholders.

This process involved exploring the existing credits, assessing their relative efficacy, and addressing gaps by referring to our analysis and common best practices for data centres, such as EN 50600-5-2.

Furthermore, the SWOT analysis methodology was employed to identify and evaluate the strengths, weaknesses, opportunities, and threats of LEED certification for data centres. This analysis reflects environmental opportunities, certification incentives, regulations and external incentives and practical challenges. This analysis aims to provide a comprehensive overview of the current certification framework and suggest areas for improvement.

3.7 Scoring Scheme Verification

After proposing the new scoring schemes, verification is conducted to answer the following research question:

R.Q.7- Does the new scoring schemes better reflect data centre environmental savings?

The new scheme was applied to the 5 case studies to determine if it accurately reflects actual savings and opportunities. This verification process involved comparing the new scores with the actual environmental performance of the data centres.

3.8 Conclusion

This chapter outlines the comprehensive methodology designed to answer the seven key research questions posed by this study, focusing on the effectiveness of LEED certification for data centres, identifying gaps, and proposing a new scoring scheme to better reflect environmental performance. The methodology ensures that each research question is systematically addressed through data collection, analysis, and verification.

The chapter begins by reviewing the literature to frame the research questions, particularly in relation to the rapid growth of data centres and their environmental impact. A robust data collection process follows, utilising the USGBC database of LEED-certified data centres and incorporating additional information on grid intensity, emissions, and transportation infrastructure. This data serves as the foundation for analysing current certification practices.

The data analysis involves both a meta-analysis of certification trends and a detailed statistical analysis of specific LEED credits, especially those with the greatest potential for environmental impact. Mathematical modelling is applied to quantify potential carbon savings from various credits, leading to the development of a new, flexible scoring system tailored to data centres.

To validate the new scoring system, a verification process is carried out using case studies. This allows for a direct comparison between the proposed model and actual environmental savings, confirming the model’s accuracy and practical applicability.

The next chapter presents the Meta-Analysis and Statistical Analysis of data centre attainment for LEED certification.

Chapter 4. Analysis of Existing LEED Certified Data Centres

4.1 Introduction

As the demand for data centres continues to grow, there is an increasing focus on achieving energy efficiency and sustainability in their design and operation. To address these concerns, various standards and certification systems have been established to assess and recognise the sustainability achievements of data centres. One certification system is the LEED, developed by the USGBC. Yet, it's been observed that data centre operators are hesitant to fully embrace LEED certification, perceiving it as not entirely suited to their industry's specific requirements (BRE, 2019).

Building on the methodology outlined in Chapter 3, this chapter presents the findings and outcomes of the results obtained from analysing the LEED BD+C certified data centres database. The main focus lies in evaluating the effectiveness of LEED certification in reflecting the environmental impact of data centres.

The primary objective of this chapter is to provide in-depth insights into the dynamics of achieving LEED certification, particularly highlighting adoption patterns, growth trends, and the specific credit performance metrics of data centres in securing certification. The analysis covers geographical spread, certification growth and level. It also covers the data centre’s approach to certification. It studies the most and least achieved credits, including their predictability.

This chapter comprehensively explores LEED BD+C certified data centres and is structured as follows. In Section 4.2, the meta-analysis focuses on the geographical distribution, certification uptake trends, and the range of certification levels achieved. Section 4.3 then conducts an in-depth credit scoring analysis, detailing data centres' most and least frequently achieved credits, assessing their predictability and analysing reasons and factors impacting their attainability. Following this, Section 4.4 thoroughly discusses these findings. The chapter concludes in Section 4.5, synthesising the findings and outlining potential directions for the research.

4.2 Meta-Analysis Results

In this section, we present a meta-analysis exploring the LEED certifications trend among data centres. Our research is grounded in a dataset of 84 certifications extracted from the USGBC over the course of a decade (2014-2024). This selection is based on the fact that prior to 2014, no data centres were certified under the specific LEED criteria introduced in LEED v4, which included tailored standards for data centres. The dataset is up to date as of February 2024.

This analysis aims to provide a clear overview of the geographic distribution of these certifications, how their uptake has changed over time, and the range of certification levels data centres have achieved. These are discussed in the subsequent three subsections. The evaluation uncovers the pattern that may reflect the influence of regional sustainability policies and market forces.

4.2.1 Geographical Spread

The initial classification focuses explicitly on categorising the spread of LEED-certified data centres based on their geographical location. The examination of the geographical distribution of these data centres provides insights into the extent of the adoption and implementation of LEED practices across different regions. Figure 4.1 and Figure 4.2 illustrate the percentage of LEED certified data centres distributed across different countries and geographical areas, respectively, highlighting the locations where certifications are prevalent.

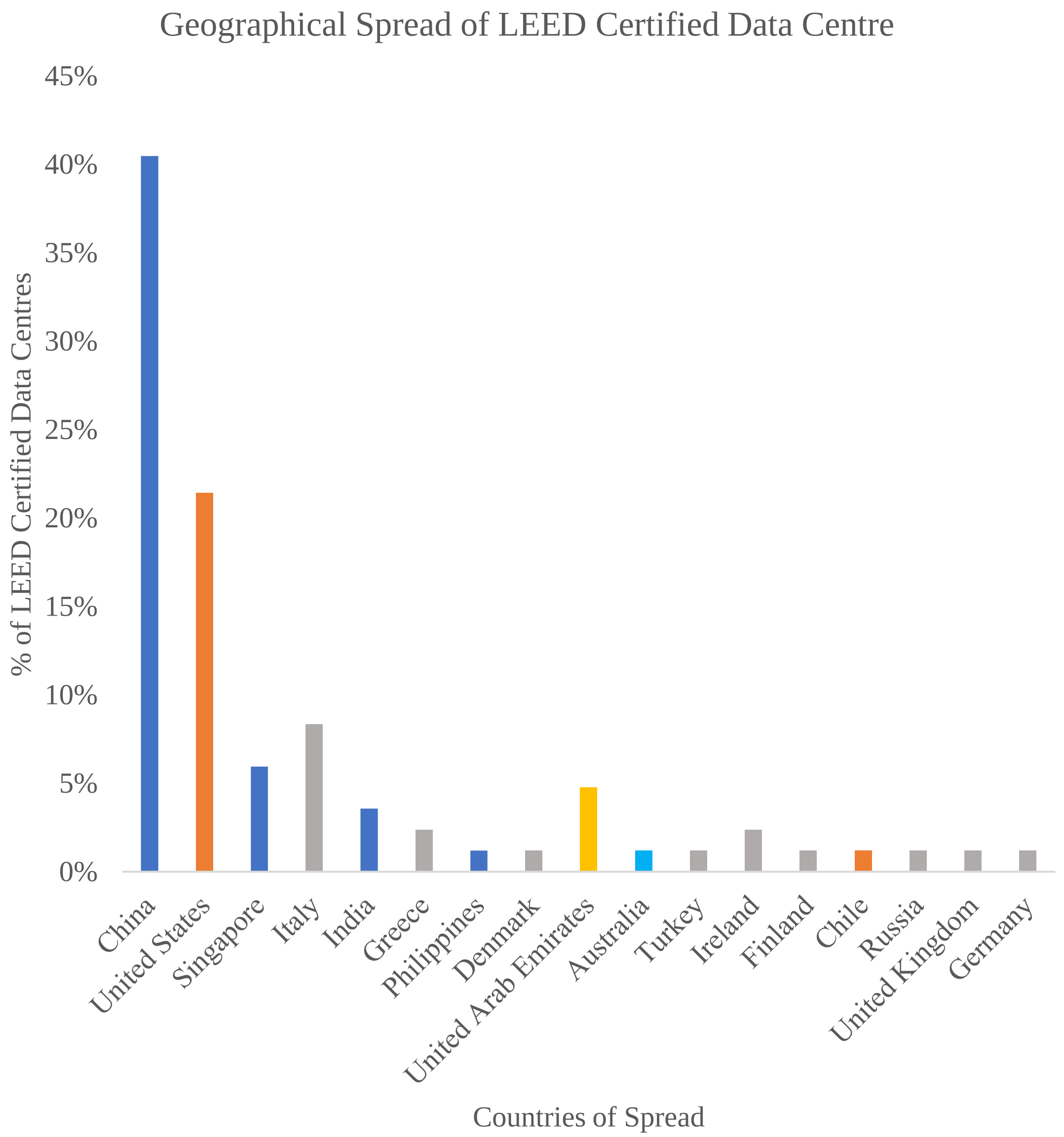

Figure 4.1 Percentage of LEED Certified Data Centres in Different Countries

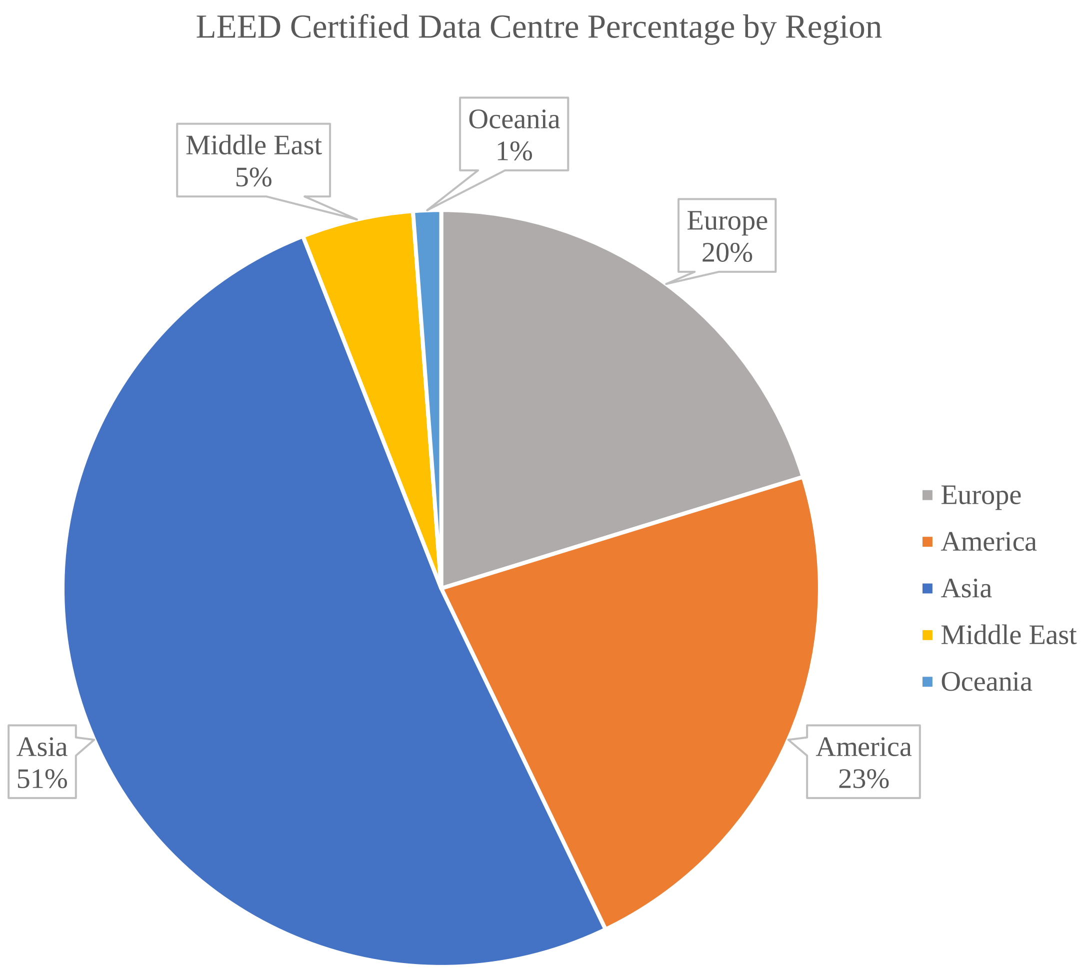

Figure 4.2 Spread of LEED Certified Data Centre by Region

As illustrated in the figures above, the distribution of LEED certifications for data centres varies across regions, with specific areas showing a higher concentration. This geographical spread can be attributed to several factors. The global drive towards net zero carbon emissions and sustainable development has particularly emphasised adopting green building principles, increasing the pursuit of relevant certifications.

Among the regions and countries with LEED certified data centres, the analysis shows varied numbers of certifications. Asia distinguishes itself as a forerunner in the number of LEED certified data centres under LEED BD+C v4 and v4.1 frameworks, while Australia has a modest 1% share of the total LEED certified data centres.

The United States, as the birthplace of LEED, has a significant concentration of LEED certifications. However, China leads in data centres, accounting for over 40% of LEED certified data centres. This considerable presence aligns with USGBC annual reports, which show China's consistent leadership in LEED certified projects outside the United States (USGBC, 2024b; USGBC, 2019; USGBC, 2023; USGBC, 2022). Although China has its own Three Stars green certification, LEED retains its appeal there. China has made significant efforts in the past two decades to promote the construction of green buildings, which are typically certified through rating systems such as LEED and Three-Star. Business and industrial buildings tend to prefer LEED, while residential buildings often opt for Three-Star certification (Zuo, 2019).

China's status as the largest carbon emitter has increased pressure to achieve carbon neutrality, leading to implementing various standards and policies for this goal by 2060 (Liu, et al., 2023). The focus on data centres becomes particularly relevant in this broader environmental context. The Chinese government has introduced measures to promote green data centres, such as setting industry standards, providing incentives for energy-saving technologies, and encouraging using renewable energy sources. The Technical Rules for Green Data Centre Building Evaluation, introduced in 2015, aim to promote green data centres and improve their energy efficiency and environmental protection levels (Li, et al., 2023). In line with these national policies, several data centre providers in China are actively contributing to these goals. For example, GDS, a prominent Chinese data centre provider, has pledged to achieve carbon neutrality by 2030. As announced in 2022, this commitment includes securing LEED certification for their data centres, ensuring that all new facilities will be designed per the LEED framework and other green buildings (GDS, 2022).

Thirdly, Europe has 20% of the LEED certified data centres. The region is committed to sustainability and the green transition, especially in the context of data centres. The aim is to transform these facilities into environmentally friendly, sustainable, and energy-efficient data centres by 2030, in line with the EU Green Deal. They are encouraged to improve their energy efficiency, explore methods to reuse waste heat and increase their use of energy sources to achieve carbon neutrality (EU Commission, 2022a).

Despite numerous regulations aimed at fostering sustainability across the European Union, LEED is still less common in Europe. One contributing factor is that while LEED has global recognition, BREEAM is more widely utilised in Europe to assess building sustainability – including data centres. The 2015 RICS report ‘Going for Green’ highlights that BREEAM has an 80% market share across Europe for sustainable building certification (RICS, 2015). The framework of BREEAM aligns with EU standards and policies, making it well-suited to the region’s sustainability objectives. However, EU data centre operators and consultants prefer the EU Code of Conduct, ISO, and EN standards over other options (BRE, 2019).

LEED certified data centres are gaining traction in the Middle East, particularly in the United Arab Emirates. These certifications account for 5% of global certifications, placing the Middle East fourth among regions with LEED data centre certifications. Notably, while the UAE is at the forefront in current rankings, several data centres in Saudi Arabia are advancing towards LEED certification, with some already achieving pre-certification status (USGBC, 2024c). It is observed that UAE and Saudi Arabia have been ranked between the top 10 for LEED-certified projects in 2021 and 2023, respectively (USGBC, 2023; USGBC, 2022). This trend reflects a growing momentum towards obtaining these certifications in recent years within the region. Furthermore, the increasing adoption of LEED certification, particularly for data centres, signifies a commitment to environmental sustainability and digital advancement, indicative of a strategic shift towards integrating sustainable practices in tandem with technological progress.

Key strategic initiatives such as Saudi Arabia's Vision 2030 and the UAE National Agenda are instrumental in driving this shift. These plans aim to diversify from oil dependency and stimulate investment across various sectors, including technology, to foster private sector expansion and more innovative sustainable development (KSA Government, 2024; UAE Government, 2024).

The focused development of smart cities and technological hubs reinforces the significant roles of the UAE and Saudi Arabia in the data centre investment landscape. According to a JLL report, these nations are integral to expanding data centres in the Middle East (JLL, 2023). The dedication to sustainable development and smart urban planning is anticipated to lead to a marked increase in LEED certified facilities within these nations. As a result, this has led to an increased focus on establishing green data centre networks to support sectoral transitions.

Lastly, Australia ranks last among the countries with LEED certified data centres. The presence of the national green building certification, Green Star, which also addresses data centre solutions, plays a significant role in the country's lower rate of LEED certification. Green Star, described as LEED's Australian cousin, was initially informed by both LEED and BREEAM and shares a common approach with these certifications (Bondareva, 2007). This alignment with a locally developed standard reflects a preference for national certification systems over international ones in Australia, resonating more closely with the country's specific conditions and sustainability requirements.

Having concluded the analysis of regional distribution, the next section of the study focuses on tracing the growth of LEED certification over time.

4.2.2 Tracing the Growth

In the second classification of our meta-analysis, we turn our attention to the chronological trends of LEED certification among data centres. This section aims to shed light on the evolution of LEED certification over the past few years. Figure 4.3 highlights the growth in interest and adoption of LEED certification within the industry.

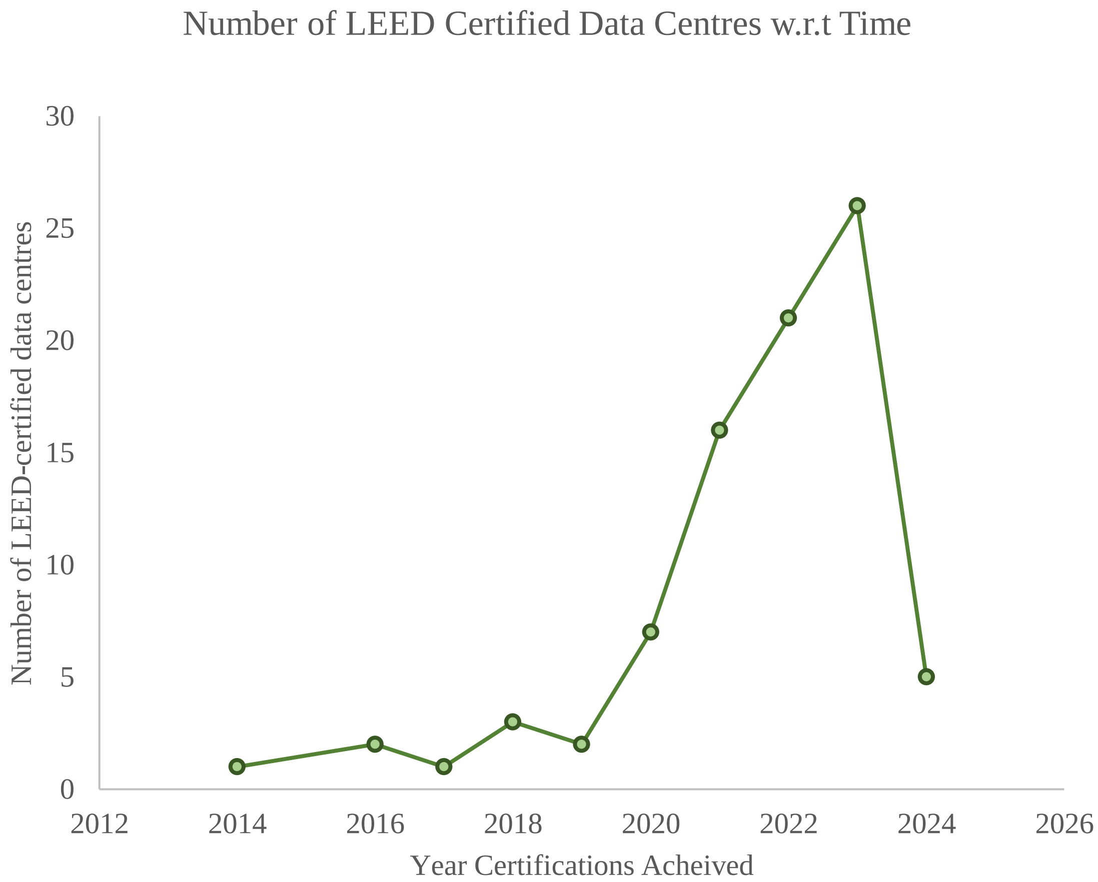

Figure 4.3 Annual Growth in LEED Certifications for Data Centres

The graph indicates a marked increase in the pursuit of holistic LEED certification, particularly from 2020, reaching a peak in 2023. Remarkably, this upward trend continues into the first quarter of this year (2024). Approximately 32% of all LEED-certified data centres achieved certification in 2023 alone, driven by the pandemic effect, regulatory pressures and the rising demand for sustainability, as discussed in the section 4.2.1. The curve demonstrates a rapid adoption and an increasing urgency among data centres to obtain LEED certification in recent years.

This growth correlates with the expansion of the global data centre construction market, valued at US$ 301.8 billion in 2023 and is projected to grow by 10.5% annually, reaching US$ 622.4 billion by 2030 (Prescient & Strategic Intelligence, 2024). The COVID-19 pandemic accelerated this industry's expansion, fostering a surge in remote work, online learning, and digital services. Consequently, global internet bandwidth rose by 28% in 2022, amplifying the demand for data centre capacity (Weissberger, 2022).

Additionally, there is an increasing awareness of data centres' environmental impact. Concerns about energy consumption levels have highlighted the need for sustainable practices (Bashroush, et al., 2016). This awareness has catalysed a shift towards green, low-carbon data centres. Regulatory changes and the rising demand for sustainable practices have also played pivotal roles. Regions such as China, the Middle East, and the EU are expanding sustainable regulations, influencing this trend (Li, et al., 2023; JLL, 2023; EU Commission, 2022a).

Moving on from the analysis of growth trends in LEED certification for data centres, the following subsection assesses the certification achievement levels.

4.2.3 Assessing Certification Levels

In this subsection of our meta-analysis, we explore the distribution of LEED certification levels among data centres, with a range spanning from Certified to Platinum. Figure 4.4 illustrates the proportion of analysed data centres attaining each level.

Figure 4.4 Distribution of LEED Data Centre Certification Level

The figure details the proportion of data centres at each certification level, showing a significant majority (over 77%) achieving Gold certification. Despite the higher expenses linked to green building certifications, this trend is influenced by factors such as branding, marketability, sustainability objectives, building performance, and value (Abraham, et al., 2022).

Policy incentives play a crucial role in promoting these higher levels of certification (Adekanye, et al., 2020). The USGBC Policy Library, for instance, lists over 200 policies encouraging or mandating advanced LEED levels (USGBC Policy Library, 2024). For example, Chandler City's Resolution 4199 requires LEED Silver for new municipal buildings over 5,000 square feet and applies to significant renovations. Importantly, this policy offers escalated incentives for private projects that aim for higher certifications than Silver, such as Gold and Platinum, thereby fostering a drive towards more advanced sustainability certifications (USGBC Policy Library, 2024).

Furthermore, financial incentives are crucial, particularly in Asia. For example, in India, introducing incentives led to a substantial increase in certified projects, surpassing 1500 buildings post-incentive implementation (Basten, et al., 2018). Similarly, financial tools like Green Bonds encourage attaining higher certification levels, exemplified by Dubai's finance framework demanding a minimum "Gold" LEED certification for eligibility (Dubai Islamic Bank, 2022).

Moreover, data centre operators are increasingly pledging to achieve LEED Gold certification. For instance, ST Telemedia Global Data Centres (STT GDC) has committed to achieving LEED Gold for all new data centres as part of their goal to become carbon-neutral by 2030 (STT GDC, 2021). Similarly, Microsoft has committed to pursuing LEED Gold certification for its newly built data centres, leveraging the USGBC's LEED volume program to streamline the certification process across multiple facilities (Smart Energy Decision, 2017; Microsoft, 2024). This reflects an industry-wide trend towards higher certification levels.

Next subsection provides an overall meta-analysis summary.

4.2.4 Overall Analysis

The growth of LEED-certified data centres from 2014 to 2024 reflects an increased emphasis on sustainability within the industry, particularly driven by rising awareness, regulatory pressures, and the expansion of the global data centre market. Notably, post-2020, there has been a marked acceleration in certifications, partly due to heightened sustainability regulations in regions such as Europe, China, and the United States. This regulatory surge, combined with growing corporate Environmental, Social, and Governance (ESG) commitments, has pushed data centre operators to pursue higher certification levels to meet both regulatory and market demands.

Geographical trends in LEED certification show distinct patterns. China, leading with the highest number of certified data centres, owes this to its aggressive infrastructure development and stringent government sustainability targets. In contrast, Europe has traditionally favoured BREEAM, particularly in countries like the UK and the Netherlands. However, recent years have seen LEED gain traction, especially as multinational corporations increasingly adopt globally recognised standards to meet ESG goals. The United States also shows consistent growth in certifications, driven by both regulatory incentives and a growing market demand for greener facilities.

The year 2020 marks a turning point, with a sharp rise in certifications continuing into 2024. This surge can be attributed to the pandemic-driven demand for remote work and digital services, emphasising the need for sustainable practices in the data centre industry. As digital services rapidly expanded, the urgency to certify facilities under sustainability frameworks also grew. By 2023, approximately 32% of all LEED-certified data centres received their certification. This trend reflects not only the industry's growth but also a shift towards environmental accountability, propelled by regulatory and corporate sustainability initiatives.

The majority of data centres are targeting higher certification levels, with Gold being the most frequently achieved. This trend underscores the increasing importance of meeting rigorous environmental standards, which are often mandated or incentivised. Furthermore, as ESG considerations become central to corporate strategies, LEED certification has become an essential tool for boosting brand image and demonstrating leadership in sustainability. Achieving a high LEED certification level—particularly in industries where environmental credentials are crucial—has further incentivised operators to pursue Gold and Platinum certifications.

Moving forward, we explore the credits scores achieved in the data centre industry. This analysis provides valuable insights into the focus areas within LEED-certified data centres, revealing key trends and priorities in attainability efforts.

4.3 Credit Scoring Analysis Results

Following our meta-analysis and assessment of the growing trends in data centre sustainability and the commitment to higher LEED certification levels, it becomes increasingly important to study which LEED credits data centres achieve and how they approach these certifications. We conducted an in-depth statistical analysis of the scorecard dataset extracted from USGBC. Statistical techniques were employed to analyse the dataset. The analysis allowed us to derive insights on data centre achievement of individual credits. We used descriptive statistics and mathematical equations to create candlestick plots, illustrating the most and least attained credits and the predictability of achieving these credits.

The analysis aims to demonstrate each LEED credit's attainment levels and frequency across the data centre industry. Several factors influence the attainability of LEED credits within data centre projects. These factors include the technical feasibility of attempting credits, documentation effort, and cost-effectiveness. Moreover, other important factors include the unique characteristics of each project and the relevance of each credit to the specific context of data centres.

The candlestick charts for each category represent the high and low scores, demonstrating the variability in scoring for each credit. This section analyses all the LEED credit categories and related credits.

4.3.1 Statistical Techniques Employed

To evaluate the credits attained by data centres under LEED, we applied a series of mathematical and statistical techniques. This section outlines the key variables and equations used to statistically analyse the scores of various credits.

The high and low scores are calculated to present the most frequent score boundaries, highlighting where most data points and scores are concentrated.

$$\text{High Score} = \begin{cases} Max, & Avg + \sigma > Max \\ Avg + \sigma, & Avg + \sigma < Max \end{cases} \quad \text{Eq 4.1}$$

Where,

The **high score** identifies the upper range of typical performance, incorporating the average and the variability of the scores.

Avg, Denotes the average, referring to a central or typical value for a set of data.

σ, Represents the standard deviation, which is a measure of the amount of variation or dispersion in a set of values. It indicates how much the values in a dataset differ from the mean (average) of the dataset.

Max, Refers to the maximum score that is attained in the dataset, indicating the peak performance attained by a data centre for a given credit.

On the other hand, the low score metric indicates the minimal attainment level among data centres.

$$\text{Low Score} = \begin{cases} 0, & Avg - \sigma < 0 \\ Avg - \sigma, & Avg - \sigma > 0 \end{cases} \quad \text{Eq 4.2}$$

Where,

The **low score** identifies the lower range of typical performance, accounting for the average and the variability of the scores.

Additionally, Min, the **Minimum Value**, is observed in the candle chart. This refers to the lowest score observed in the dataset, indicating the least performance attained by a data centre for a given credit.

These metrics help to understand the baseline performance and the extent to which data centres perform in attaining credits. The values are presented in a candlestick chart, where the range and variability of scores are clearly illustrated. The candlestick chart effectively displays the upper and lower boundaries (high and low scores) and highlights where most scores fall within this range, providing a visual representation of the performance distribution.

The following section presents the results for the candlestick charts across all categories.

4.3.2 Location and Transportation

The Location and Transportation category in LEED certification focuses on maximising efficiency based on transportation methods, parking availability, and strategically selected locations that reduce travel distances (USGBC, 2024d). Figure 4.5 illustrates the distribution of score achievement for the credits, which comprises seven credits within this category.

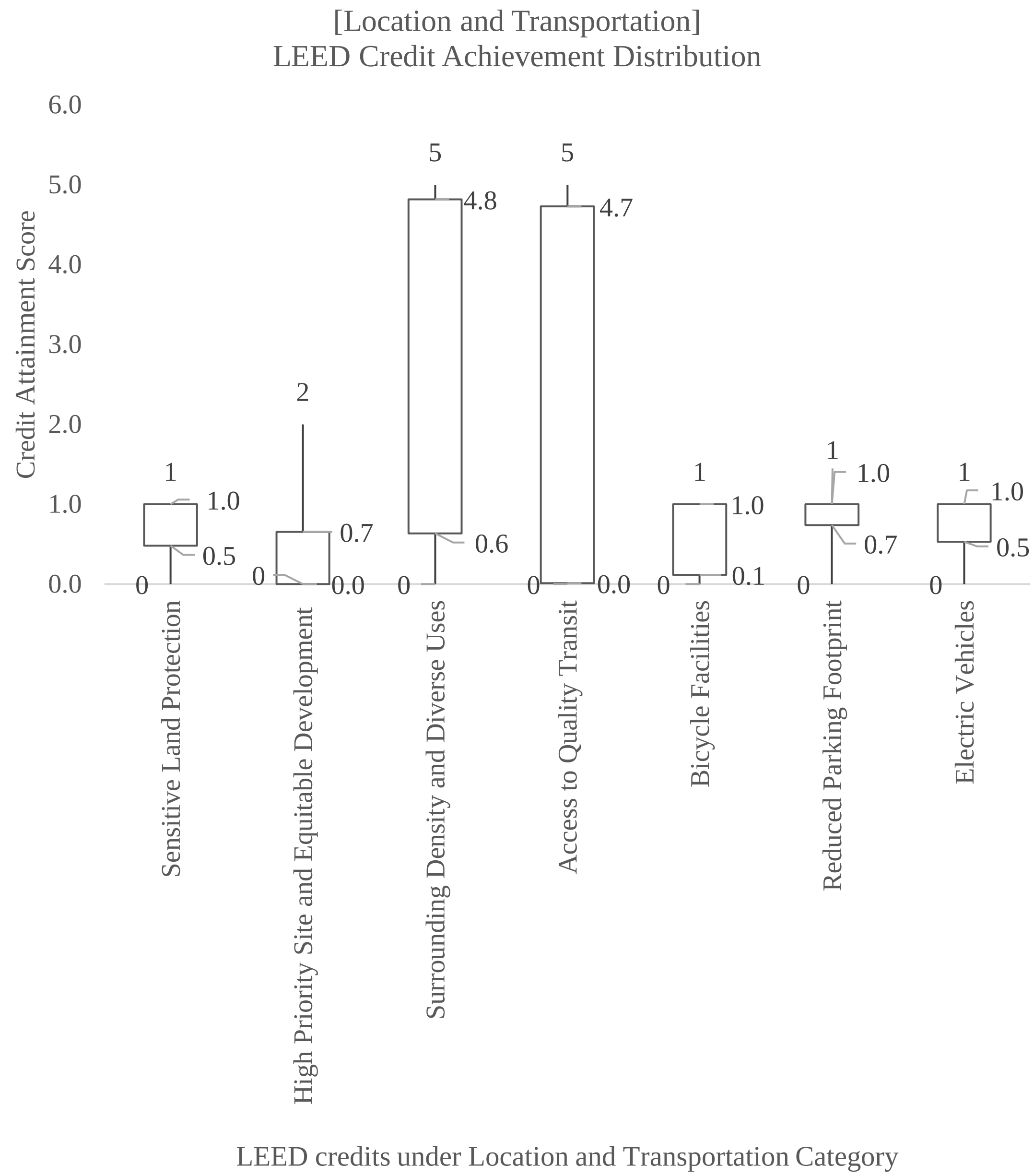

Figure 4.5 Attainability of LEED Credit Scores Within the Location and Transportation Category

Each candlestick in the chart represents a specific credit. The main body of the candlestick illustrates the range where the majority of scores lie, with the high and low scores marking the range's boundaries. The wicks, extending from the body, capture the maximum and minimum scores, providing insight into the full scope of achievement levels.

The chart shows the narrowest body corresponds to Reducing Parking Footprint. This indicates that this credit has most predictable outcome, with most cases having similar performance. This credit is positioned at the upper end near the total score, indicating a high achievement level. It displays that the high range boundary is equal to the maximum score achieved, representing the highest score for this credit. This positioning suggests that most data centres approach this area successfully, often nearing the total possible points.

A wider candle body indicates lower predictability due to high variability in scores. The widest body corresponds to Access to Quality Transit in this category. It shows scores ranging from 0 to 4.7, suggesting wide variability and non-predictable average attainment. The maximum score achieved, represented by the upper wick, is 5 points, the total points allocated. Scores often tend to be closer to the lower bound, suggesting that achieving high marks in this area is less common for data centres.

The High Priority Site and Equitable Development credit shows a narrower range of scores, situated lower on the scale, signifying a trend towards lower achievement levels.

Another unpredictable credit is surrounding density and diverse uses. This credit shows scores ranging from 0.6 to 4.8, suggesting wide variability and non-predictable average attainment. The criteria for this credit have been adjusted between LEED versions 4 and 4.1 to better meet data centres' needs. However, neither version fully addresses their specific challenges. Version 4 focuses on proximity to living areas and services, while version 4.1 adjusts to include easy access to transport routes such as airports and highways, more commonly associated with warehouses. There is a lack of addressing designed requirements for data centres' unique nature and operations.

Similar to the Reduced Parking Footprint credit, the Electric Vehicles and Sensitive Land Protection credits have a narrow body that lies near the upper end of the scale, indicating higher achievement levels with low variability. In contrast, the Bicycle Facilities credit shows a wider body, indicating higher variability and unpredictability in scores.

The ability to achieve credits in this category displays a certain level of unpredictability. Variability primarily arises from the data centre's location and the travel patterns of its staff. A data centre's staff size can significantly affect the practicality of targeting specific transportation-related credits. Data centres with more staff may more readily meet the requirements for these credits, while those with fewer employees might not find it beneficial to pursue them. Thus, the number of employees and the operational parameters of a data centre are crucial in determining the feasibility of securing these LEED credits.

4.3.3 Sustainable Site

In the framework of LEED certification for data centres, the Sustainable Sites category assesses the strategies employed for site selection, development, and management to mitigate impacts on ecosystems and biodiversity (USGBC, 2024e). Figure 4.6 displays the corresponding candlestick plot for achievement scores within this category.

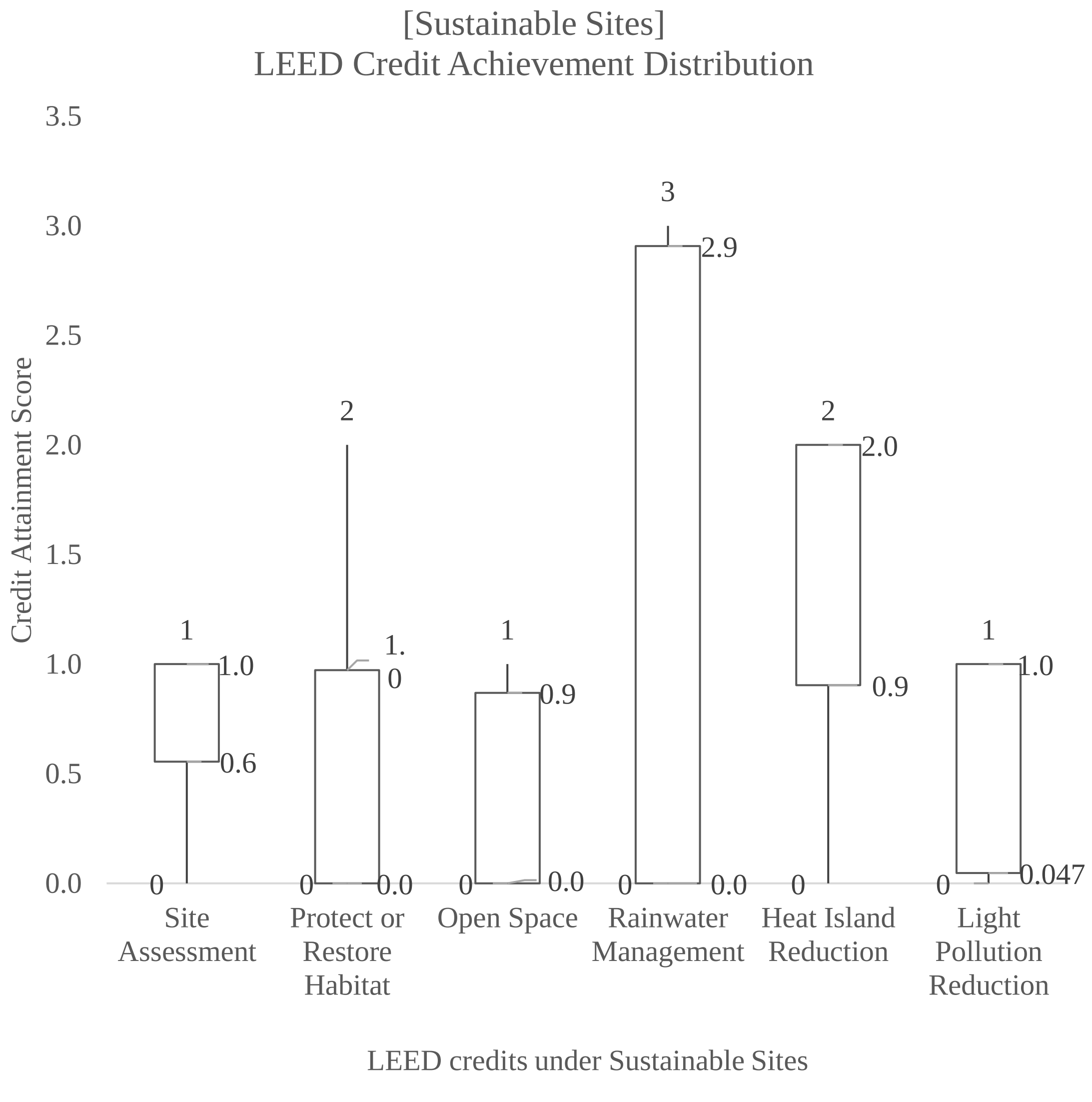

Figure 4.6 Attainability of LEED Credit Scores Within the Sustainable Sites Category

The chart indicates that most credits within this category demonstrate a wide range of scores, signalling unpredictability in attainment. Notably, most credits' trend is towards the lower end, suggesting a generally lower level of achievability and attainability by data centre operators for these specific criteria.

The least attained credit corresponds to the Protect or Restore Habitat credit, while the most unpredictable is the Rainwater Management credit, which has the widest body.

However, the Site Assessment credit demonstrates a consistent pattern of higher scores. It shows a predictable pattern of having a high score. This credit aligns with some basic requirements for environmental impact assessment regulations and directives across various countries. For instance, it includes elements similar to those in the EU Directive on Environmental Impact Assessment and the National Environmental Policy Act (NEPA) in the United States (EU Commission, 2012; US EPA, 1970). These laws require project developers to evaluate potential environmental impacts and develop mitigation strategies, principles that are similar to the LEED Site Assessment credit.

Similarly, the Heat Island Reduction credit shows higher attainment levels. This credit aims to reduce energy demands, which are a critical concern in data centre operations. This credit aligns with broader environmental and energy efficiency goals.

4.3.4 Water Efficiency

The Water Efficiency category focuses on the strategic management and conservation of water resources through the implementation of technologies and practices designed to reduce water consumption (USGBC, 2024f). This category addresses various types of water usage, including outdoor, indoor, and process water. Notably, indoor water credit represents 54% of the total score within this category. Figure 4.7 illustrates the candlestick plot for achievement scores within the Water Efficiency category, highlighting the distribution of scores across different credits.

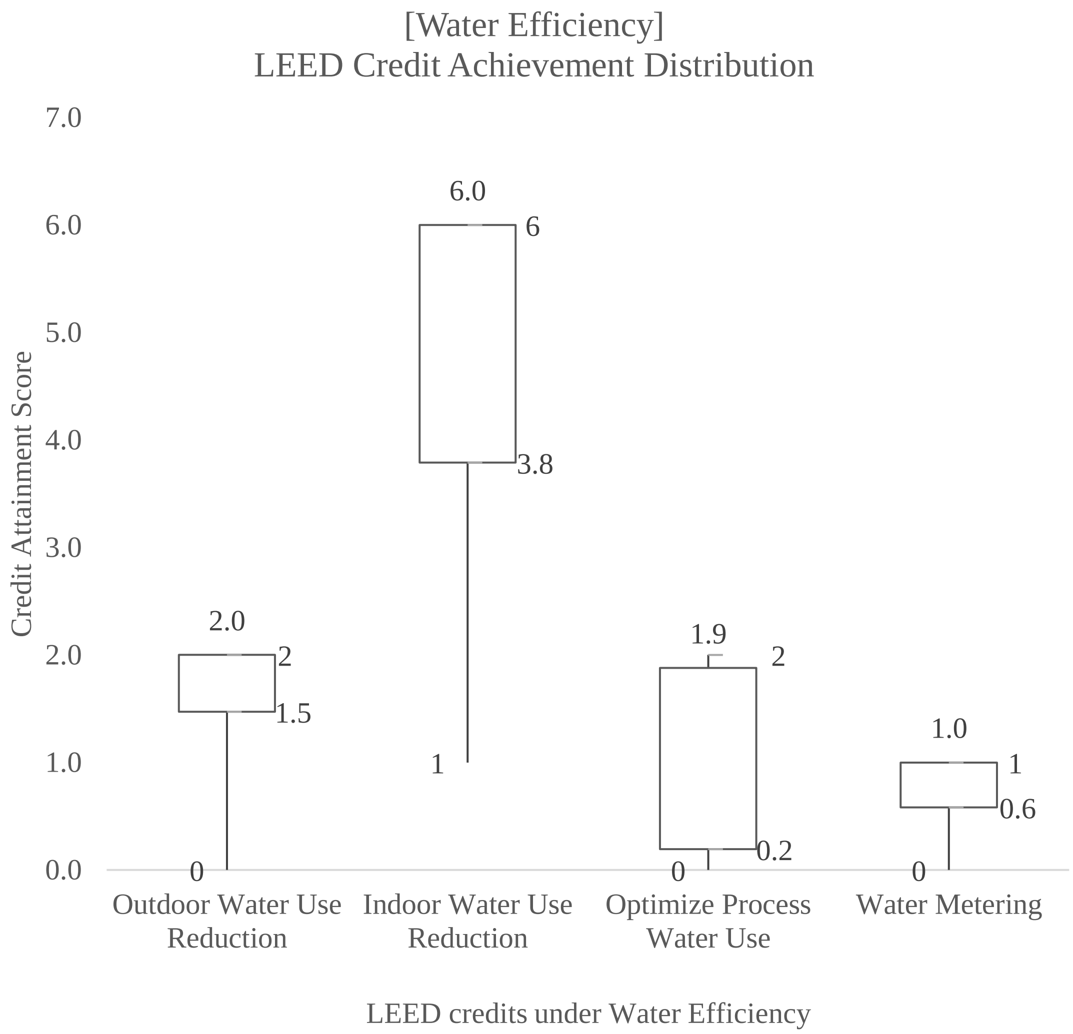

Figure 4.7 Attainability of LEED Credit Scores Within the Water Efficiency Category

The plot reveals a high and predictable level of attainment for most credits. The most predictable to have the highest attainment in this category is displayed to be the Outdoor Water Use Reduction.

However, the Optimise Process Water Use credit displays the lowest predictability and attainability. This credit focuses on water used in cooling towers, requiring a basic assessment of these facilities. Cooling towers are significant water consumers in data centres. For example, a 1MW data centre can consume up to 18,000 gallons of water per day for heat dissipation if cooled chillers and cooling towers are used (Sharma, et al., 2009).

However, water demands in data centres vary significantly based on the cooling system used and local climate conditions. If used, technologies like air-cooled chillers or free cooling can drastically reduce these demands (Sharma, et al., 2009; Ristic, et al., 2015). Even so, the process of water credit scoring primarily focuses on cooling towers. This focus can lead to drawbacks for data centres that opt for alternative cooling solutions, even if they result in more significant water savings. This is because a sustainable practice or positive feature is implemented but does not fit within the predefined criteria or is not mentioned in the credit requirements; it doesn't qualify for points under the LEED system (Denzer & Hedges, 2011).

Despite the technologies used, there remains a significant gap in the research and transparency of water usage in data centres. This gap underscores the importance of the water metering credit, revealing that many data centres still do not implement metering systems to track water consumption effectively.

The water metering credit provides basic requirements for monitoring water usage. However, many facilities still fail to achieve this credit, indicating a need for more incentives to achieve this credit. The fact that many data centres struggle to meet even the basic requirements highlights the ongoing challenges in achieving transparency and efficiency in water usage. Additionally, more detailed metering requirements for data centres are outlined in standards such as EN 50600-4-9 (BSI, 2022).

4.3.5 Energy and Atmosphere

The Energy and Atmosphere category is a critical component of the LEED framework, focusing on the efficient use of energy resources, reduced energy consumption, and mitigation of environmental impact in buildings (USGBC, 2024g). This category is especially significant, contributing to 33% of the overall LEED score. Its influence is particularly notable during the operational phase of buildings. Data centres are known for demanding energy consumption, using up to 100 times more per square metre than office spaces (Fakhim, et al., 2011). Figure 4.8 shows the distribution of scores attainability for the energy and atmosphere credit category.

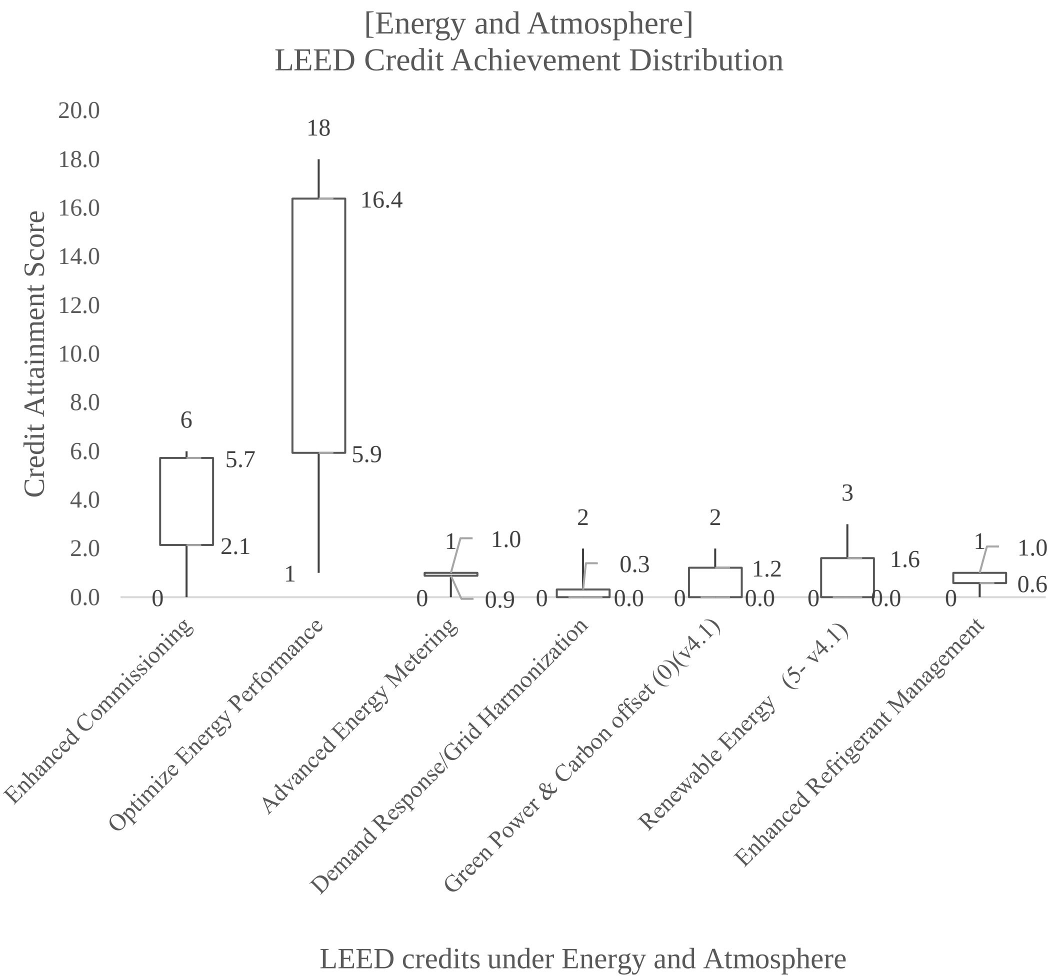

Figure 4.8 Attainability of LEED Credit Scores Within the Energy and Atmosphere Category

The plot demonstrates a generally high predictability of achieving most credits within this category. However, it also identifies specific credits with notably lower attainability rates. For instance, the Demand Response Credit has very low attainability, with most instances failing to secure any points. This could be attributed to the inherent challenges associated with the credit. Operational priorities in data centres, such as maximising uptime and performance, may present obstacles to participating in demand response programs due to the associated risks (Wierman, et al., 2014). Similarly, Renewable Energy Credit is predicted to have low attainability. The credit has been merged with Green Power and Carbon Offset in version 4.1.

Conversely, the Advanced Energy Metering Credit has an almost 100% achievement level, highlighting its importance. While the LEED Advanced Energy Metering Credit emphasises basic energy monitoring, data centres typically implement far more sophisticated and detailed metering systems, surpassing LEED requirements to ensure optimal energy efficiency and operational insight.

Credits such as Optimising Energy Performance and Enhanced Commissioning typically demonstrate moderately predictable scores and generally skew towards high attainability at the upper end. Interestingly, the Optimising Energy Performance credit reveals that, even though efficiency is crucial, some data centres have achieved certification with scores as low as one out of 18, suggesting that certain facilities may only minimally address energy efficiency credit. Moreover, the scores vary significantly, with the common lower end of the scale being around 6, implying that many don’t reach even half the available points.

Furthermore, many data centres are adhering to enhanced refrigerant management practices. This practice aligns with minimum requirements compared to regulations and data centre’s best practices such as the EU F-Gas Regulation No 517/2014 (EU Commission, 2014), the Clean Air Act Amendments of 1990 in the United States (US

EPA, 1990), and the Significant New Alternatives Policy (SNAP) Program (US EPA, 1994) and EN-50600-5-2.

On the other hand, the chart indicates that adopting green energy solutions scores in the lower range. This low attainability may be influenced by geographic location and the availability of green energy resources.

4.3.6 Material and Resources

The Materials and Resources category in LEED focuses on minimising the environmental impact through carefully selecting and managing materials and resources (USGBC, 2024h). This category covers construction materials, the building envelope, and furniture, focusing on using sustainable building materials and products, including doors, windows, finishes, and furnishings. It also considers the entire lifecycle of these items, covering extraction, production, and disposal processes. Figure 4.9 demonstrates a trend in how data centres typically achieve the various credits within this category.

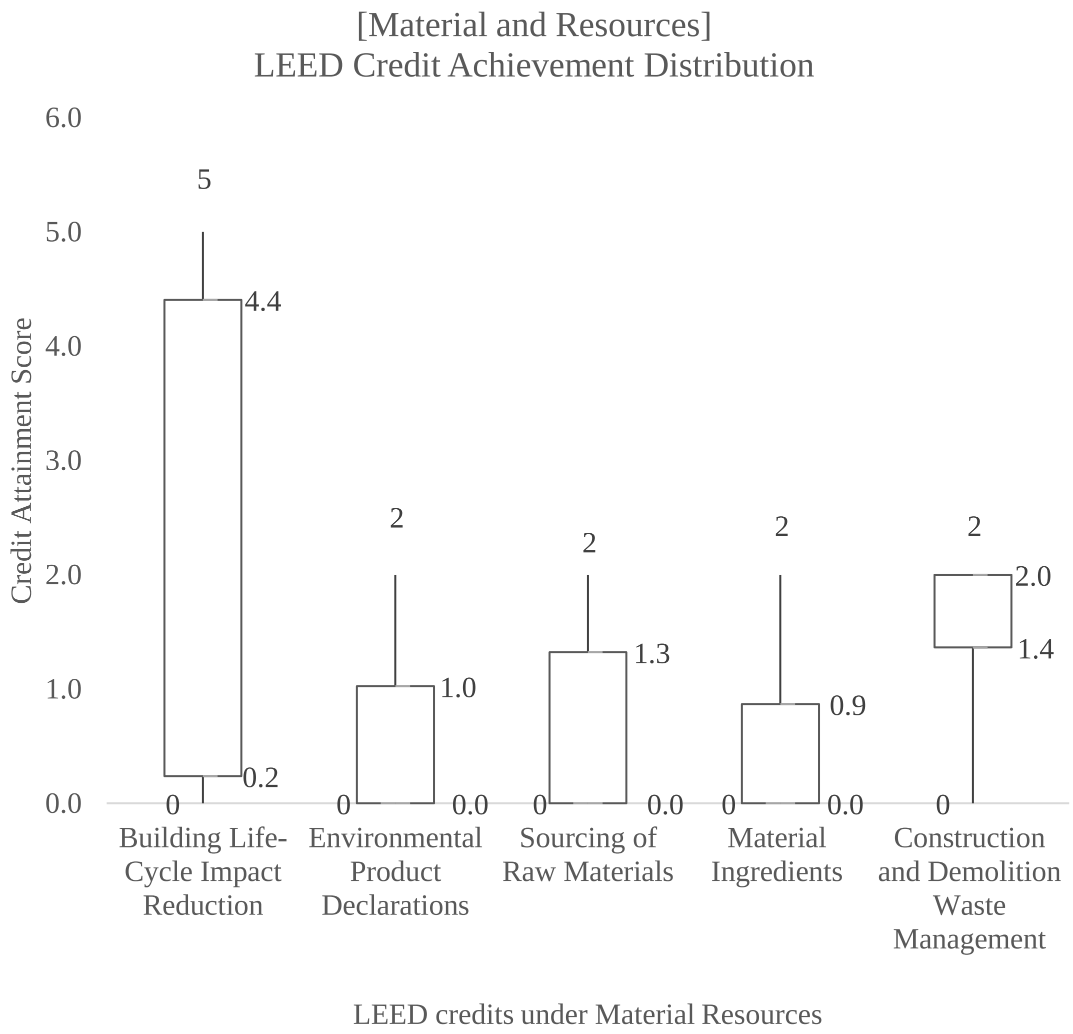

Figure 4.9 Attainability of LEED Credit Scores Within the Material Resources Category

The plot indicates that achieving high scores in this category is generally unlikely, suggesting limited success in this category. However, an exception is noted in the Construction and Demolition Waste Management credit, which shows a higher attainability rate as evidenced by its position in the candlestick chart.

Moreover, the Building Life Cycle Impact Reduction credit is the most unpredictable within this category. It is characterised by a vast body in the candlestick representation, indicating a substantial range of score variability. This variability highlights significant differences in how this particular credit is approached and achieved.

Literature has observed that data centres have long focused on operational energy efficiency and scope two emissions as key sustainability metrics. This narrow focus often leads to the broader environmental impacts throughout the entire life cycle of a data centre being overlooked (Whitehead, et al., 2015). The Building Life Cycle Impact Reduction credit typically registers scores on the lower end of the spectrum. This trend may be attributed to the fact that current tools for assessing the life cycle impacts of data centres may not be sufficiently comprehensive or readily accessible for operators (Whitehead, et al., 2015). Although the awareness of scope three emissions is increasing, this credit still has low attainability.

The least attained credit in this category is the Material Ingredient credit. This low average is due to challenges in feasibility, documentation, and the need for third-party verification.

4.3.7 Indoor Environmental Quality

The Indoor Environmental Quality (IEQ) category primarily focuses on human comfort factors, including lighting and overall environmental quality (USGBC, 2024i). Figure 4.10 displays the attainment levels within this category.

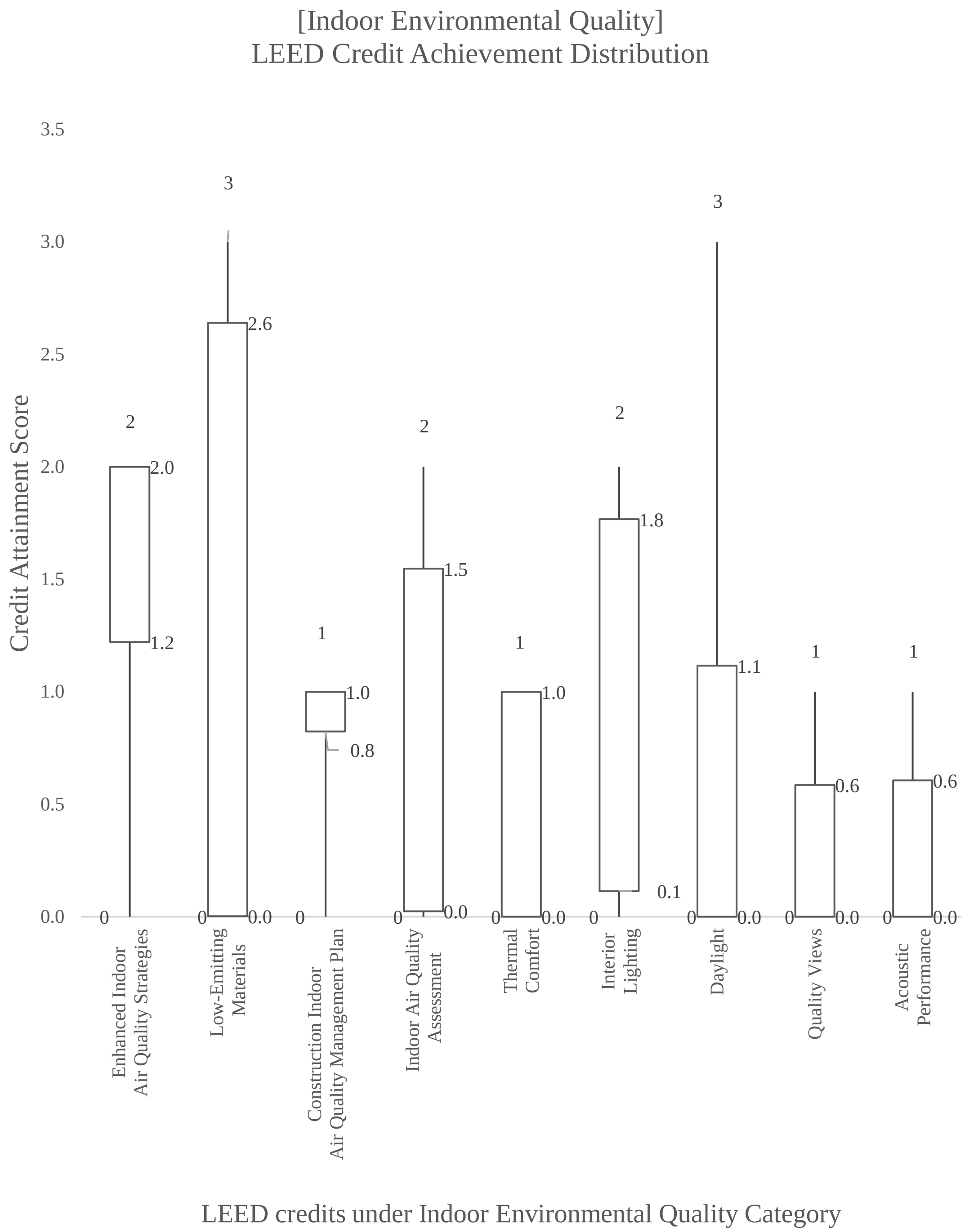

Figure 4.10 Attainability of LEED Credit Scores Within the Indoor Environmental Quality Category

The plot indicates lower credit attainment rates, with most scores tending to concentrate towards the lower end of the scoring range. It is observed that the majority of credits tend to cluster towards the lower end of the scoring range. This indicates that achieving high scores in these areas is relatively uncommon among the data centre certifications analysed. This suggests that achieving high scores in these areas is relatively unusual among the data centres analysed. However, notable exceptions include the Construction Indoor Air Quality Management Plan and Enhanced Indoor Air Quality Strategies credits. These credits show higher predictability, indicating that most data centre operators successfully attain them.

4.3.8 Remaining Credits

This subsection explores the remaining main credit, the Integrative Process, a category promoting comprehensive sustainability and enhanced project integration within LEED certification. Additionally, it covers the ten bonus point credits, which incentivise project teams to adopt early-phase analysis and continuous collaboration to optimise building performance and sustainability. Figure 4.11 illustrates the attainment levels for these specific credits.

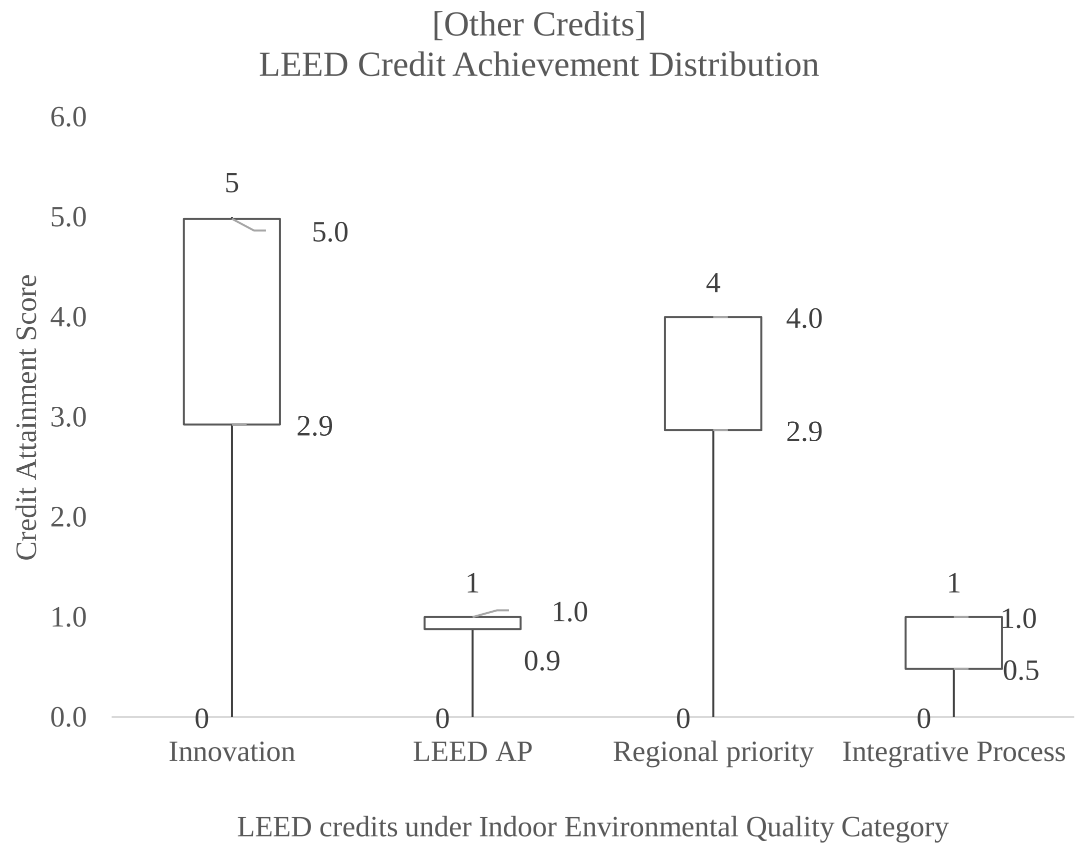

Figure 4.11 Attainability of LEED Credit Scores Within Bonus Credit and Integrative Process Credit

The plot shows high attainability and high predictability for these credits. These credits are often considered easy and don't add any substantial effort or cost to achieve them.

The subsequent section further discusses these findings.

4.4 Discussion

The rising trend in data centres attaining LEED certification reflects the sector's engagement with sustainable practices. Nonetheless, there is notable variability in how credits are achieved. Many factors impact the attainability of individual credits. Among these factors, is the characteristic of data centre, feasibility of attempting credits, documentation effort, cost of attaining, and alignment with regulations.

This section discusses the credits that are most and least frequently achieved by data centres, providing insights into areas where efforts are excelling and where they fall short. The critical analysis of the ten most and least attained LEED credits for data centres was conducted to highlight the trends in credit attainment and to assess the efficacy of the LEED framework in addressing data centre-specific sustainability needs. By examining the most frequently attained credits, we can identify which sustainability practices are being prioritised by the industry, potentially due to their ease of implementation or cost-effectiveness. Conversely, the least attained credits can reveal areas where data centres struggle to meet LEED criteria, potentially due to higher costs, technical challenges, or misalignment with the specific operational characteristics of data centres.

This analysis also helps to uncover any gaps in the LEED framework that may lead to an over-reliance on certain credits that offer minimal environmental impact ("greenwashing") while avoiding credits that could provide more substantial sustainability benefits. By identifying these trends, the research can suggest improvements to the LEED system, such as revising the scoring scheme better to reflect actual environmental impact rather than ease of attainment.

The section ranks the credits, highlighting the ten least and ten most attained credits across all categories. First, subsection 4.4.1 presents the most attained LEED credits. Next, the least achieved ones are given in subsection 4.4.2.

4.4.1 Ten Most Attained LEED Credits by Data Centres

The frequency of attainment for each LEED credit is quantitatively analysed to determine which credits are most frequently achieved. This helps in understanding the relative popularity and difficulty of different credits within the data centre industry.

The average points obtained for each credit indicate the relative convenience with which credit requirements are satisfied. Since each credit has a different total achievable point, average achieved points in different credits have no comparative value. Therefore, the Percentage Average Score (PAS) is used to help quantify and analyse which credits are the most and least achievable by data centre operators.

$$PAS = \frac{Avg}{FTS} \times 100 \qquad \text{Eq 4.3}$$

Where,

FTS, Refers to the full total score corresponding to a specific credit

Table 4.1 lists the top ten credits with the highest average scores, showcasing which areas are most frequently achieved across various data centres.

Credits Name	**Percentage Average Score**
Advanced Energy Metering	99%
LEED AP	99%
Construction Indoor Air Quality Management Plan	98%
Reduced Parking Footprint	95%
Outdoor Water Use Reduction	93%
Construction and Demolition Waste Management	93%
Regional priority	90%

Water Metering	89%
Enhanced Refrigerant Management	89%
Site Assessment	88%
Average	93%

Table 4.1 Credits with The Highest Percentage Average Score

These top ten credits contribute 15 points to the LEED score, significantly impacting the certification level.

In the breakdown of the highest achievement rates:

- Two pertain to the Energy and Atmosphere category.
- Two are bonus categories.
- Others fall under Water Efficiency, Location and Transportation, Site Selection, Indoor Environmental Quality, and Materials and Resources.

The average score of the first top 10 credits is 93%, a relatively high attainment level. The key reason behind this high average is that these credits are low-hanging fruits, easily attainable with minimal extra work, cost-effective, and in line with existing standards and regulations.

Leading the list is Advanced Energy Metering, which is crucial for monitoring and optimising energy usage within data centres. However, in this credit, basic energy monitoring is required compared to what is mandated, for example, in the EN50600 series. Similarly, water metering, which also ranks high and is an important practice, is only required at a minimum granularity compared to what is required by international best practices for data centres.

Earning the LEED AP credit involves having a LEED Accredited Professional on the team during development and implementation. Another bonus credit, the Regional

Priority, targets specific credits depending on regional priorities identified by the USGBC. This credit doesn’t require additional effort.

The Site Assessment credit typically requires straightforward documentation of site surveys. Meanwhile, Enhanced Refrigerant Management and Construction Indoor Environmental Management Plan credits expect adherence to existing standards and are often integrated into national regulations. These credits generally demand minimal additional effort and cost beyond what is required by local regulations. Hence, the high achievement level.

The Reduced Parking Footprint credit involves little effort, as data centres typically require fewer parking spaces due to low staffing levels. The Outdoor Water Use Reduction credit, applicable to the generally small irrigation requirement of data centres, encourages using drought-resistant plants or minimal irrigation techniques.

However, the Construction and Demolition Waste Management credit requires more effort to reduce construction waste and enhance waste diversion from landfills.

The following subsection explores the credits with the lowest average attainments.

4.4.2 Ten Least attained LEED credits by data centres

While certain credits are frequently achieved in data centres, others remain less commonly attained. Table 4.2 lists the top 10 least achieved LEED credits in data centres.

Credits Name	**Percentage Average Score**
Sourcing of Raw Materials	33%
Environmental Product Declarations	24%
Green Power & Carbon offset	20%
Acoustic Performance	20%
Quality Views	19%
Renewable Energy	17%
Material Ingredients	15%
Protect or Restore Habitat	14%
Daylight	10%
High-Priority Site and Equitable Development	8%
Demand Response/Grid Harmonisation	2%

Table 4.2 Credits with Least Ten Percentage Average Score Values

In the breakdown of the least achievement rate:

- Three credits fall under the Material Resources category.
- Three credits are classified under the Indoor Environmental Quality category.
- Three credits pertain to the Energy and Atmosphere category.
- One credit is from the Location and Transportation category.

In the landscape of LEED certifications, specific credits, though critical for environmental sustainability, exhibit low achievement rates in data centres. Among these are the Sourcing of Raw Materials, Environmental Product Declarations, Green Power and Carbon Offset, Renewable Energy, and the Demand Response credit. These credits carry significant environmental importance but often require substantial effort and increased costs.

Credits such as Environmental Product Declarations and Sourcing of Raw Materials necessitate comprehensive third-party verification about the sustainability and origin of materials, adding considerable time and financial overhead. Furthermore, demanding products with rapidly renewable content demands precise planning and coordination, complicating the procurement process.

Additionally, the acquisition of credits associated with Green Power and Renewable Energy introduces considerable challenges. These credits generally lead to increased operational costs because they involve purchasing certified green energy or investing in on-site renewables, which may not be consistently accessible or cost-effective. However, transitioning from fossil fuels to renewable energy is crucial as it significantly reduces emissions. Despite its importance, these credits still have very low attainment. Besides cost and feasibility, the implementation of on-site renewable energy solutions, such as solar panels or wind turbines, is particularly challenging. Not only do they require significant initial investments, but they also consume extensive land space, which can be impractical for many data centres. Consequently, operators may opt for less challenging or less costly credits that yield similar scores despite the lower incentive for the more impactful renewable energy credits.

On the other hand, there are credits that are not highly relevant to data centres. For example, architectural features such as windows are often minimised or absent. Credits such as Daylight and Quality Views are designed to enhance staff productivity and wellness through natural lighting and visual access to the outdoors. However, these features are typically not prioritised in data centre facilities, where the primary focus is on securing and maintaining the IT infrastructure with minimal staff presence. This lack of applicability makes it understandable why such credits are less frequently achieved, underlining a disconnect between standard LEED criteria and the unique operational needs of data centres.

Another particularly tricky credit for data centres is the High Priority Site and Equitable Development. While this credit promotes important goals of community engagement and equitable development, data centres inherently come with a set of rigorous requirements focusing on security, reliability, and environmental stability. These essential criteria often limit the flexibility data centre operators have in selecting sites that align with the broader objectives of this LEED credit. Although this doesn't diminish the value of the credit, it highlights the complex priorities that data centre operators must juggle, ensuring operational imperatives are met while also considering sustainable development goals.

This pattern within the data centre industry, where operators often select less stringent and more attainable credits, not only impacts overall sustainability efforts but also points to inherent limitations in the LEED system. This tendency to prioritise easier, less environmentally stringent credits reveals a need for a reassessment of how LEED credits are structured and incentivised, particularly for industries with specific operational demands such as data centres.

The following section summarises the key findings of this chapter. It outlines the future directions of this analysis, setting the stage for a deeper exploration of the implications and strategies moving forward.

4.5 Conclusion

The chapter explores trends in data centres regarding LEED certification, highlighting an increasing trend towards achieving at least a Gold level. Stricter environmental regulations largely influence this shift, the expanding data centre sector, and significant global events like the COVID-19 pandemic.

A detailed statistical analysis of LEED credits reveals a varied score range of credit attainability among data centres. Credits such as Advanced Energy Metering show consistent predictability with narrow scoring ranges. In contrast, credits associated with staff and human aspects exhibit broader scoring ranges and lower attainment levels. It is noted that credits under Indoor Environmental Quality and Material Declarations consistently record the lowest attainment levels.

The most frequently attained credits are typically the cheapest, simplest, and require the least effort. Also, some credits meet only the basic requirements rather than pursuing the higher standards seen in data centre best practices. Conversely, the least attained credits include those minimally relevant to data centres. Additionally, they encompass critically important environmental credits that are costlier and require substantial effort, often dependent on third party involvement and other external factors.

Looking ahead, Chapter 5 explores the potential environmental savings from emission-related credits, identifying scoring gaps.

Chapter 5. Environmental Credits Impact Assessment

5.1 Introduction

The adoption of LEED certification by data centre operators is on the rise. However, significant gaps remain in addressing these facilities' unique functionalities and specific challenges. The LEED criteria do not adequately cover the distinct energy consumption patterns and sustainability considerations explicitly tailored for data centres (Moud, et al., 2020).

Furthermore, there is a notable gap in the LEED scoring system. It fails to fully reflect the actual sustainability performance of facilities (Denzer & Hedges, 2011). LEED applies similar scoring criteria to data centres similar to other building types (USGBC, 2024j). This one-size-fits-all approach applies uniform scoring criteria to all buildings, including data centres, regardless of their distinct operational demands and energy consumption characteristics. Moreover, the LEED scoring mechanism currently rewards positive achievements based on current credits' requirements but does not penalise non-sustainable practices or consider the non-applicability of certain features (Denzer & Hedges, 2011). When required sustainable practices are not applicable, no points are awarded, affecting the final score and certification level. This system can create complications, especially for data centres, where several LEED practices may not directly apply or be essential to their operations (Moud, et al., 2020).

This gap highlights the need for a tailored approach in environmental and operational certifications that better aligns with the specific operations of the data centres. These facilities are primarily driven by the continuous operation of servers and hardware, significantly contributing to carbon emissions (Bashroush, et al., 2020).

Results from Chapter 4 reveal an imbalance in compliance with practices. The top 10 most frequently attained credits highlight a notable omission of operational credits that directly impact emissions. Additionally, the least frequently achieved credits include crucial areas such as Renewable Energy and Green Power. These findings underscore the challenges in aligning LEED certification goals with data centres' operational energy and environmental priorities.

This chapter demonstrates the data centre's maximum environmental savings possible across various types and regions using mathematical models and equations created for this exercise. The primary objective of this chapter is to assess whether LEED scores accurately reflect the actual emission savings achieved by data centres. It presents the results of calculated maximum opportunity savings from credits and compares these to the allocated LEED scores. Thereby evaluating how well the allocated LEED scores represent the environmental impact and savings.

The chapter is structured to initially show the detailed calculations and equations applied to one of the case studies in Section 5.2. Next, the variables and constants used in the equations are presented and explained in Section 5.3, along with the corresponding results. The results and opportunities from the emission savings from LEED credits across five case studies are analysed in Section 5.4. Following this, Section 5.5 presents a comparison of the actual savings achieved to the allocated LEED scores. In Section 5.6, the assessment is further verified by analysing two actual levels of certification—Certified and Gold—and comparing their scores to their actual environmental impacts. Further discussion is then held in Section 5.7, and the chapter concludes in Section 5.8, summarising the findings and outlining potential research directions.

5.2 Detailed Calculation of Environmental Savings for Case Study 1

This section provides a detailed example of how the mathematical models and equations are applied in practice. Five case studies are analysed in the model to assess the potential environmental savings opportunity. Each represents a different type, size, and geographical location of data centres. The selected case studies represent real-life data centre scenarios chosen to reflect a range of key characteristics that impact sustainability performance. They cover different sizes, operational types, and geographical locations, accounting for variations in environments, grid intensities, and climate conditions. These case studies encompass a broad set of factors, ensuring the analysis captures the main differences in data centre operations. These variations affect several factors, such as grid intensity, availability of public transportation, and cooling requirements, which are essential in calculating potential savings and environmental impacts. Key parameters for each case study are shown in Table 5.1.

	Data Centre Type	**Location**	**Number of staff**	**IT load (kW)**	**PUE**	**Area (m^2)**
Case Study 1	Enterprise	Saudi Arabia	16	500	2.3	2,250
Case Study 2	Colocation	Saudi Arabia	15	600	2.2	2,700
Case Study 3	Colocation	Belgium	12	1,500	1.7	6,750

Case Study 4	Enterprise	Ireland	7	300	1.9	1,350
Case Study 5	Hyperscale	Sweden	150	100,000	1.2	450,000

Table 5.1 Key Parameters of the 5 case studies

To ensure clarity and demonstrate the practical application of the models, a sample calculation is provided using one representative case study as an example. A step-by-step walkthrough of the calculations is given, showing how the equations are applied to the case studies and illustrating the actual savings opportunities from data centres following the LEED certification framework.

Each equation is tailored for different LEED credits to calculate CO_2 savings according to their requirements. This approach not only quantifies CO_2 reductions but also accounts for any potential increases in emissions due to these credits. These equations cover a range of environmental credits across the LEED categories, ensuring a comprehensive assessment of their impact. The model presented in this chapter specifically focuses on environmental credits that have a direct impact on CO_2 emissions from the data centre. Categories like Water Efficiency and Indoor Environmental Quality were excluded because they primarily address indoor water use and occupant comfort, which have minimal influence on a data centre's carbon footprint. Our focus is on credits that directly reduce CO_2 emissions. The maximum savings are calculated based on assuming the best-case scenario of achieving the full credit. The equations present the maximum annual CO_2 savings a specific credit achieves in tonnes of CO_2.

The model calculates savings by considering each credit independently, without accounting for the overlap effects of multiple credits. It evaluates savings based on each credit relative to the baseline or design rather than incorporating the cumulative impact of various interventions. For example, achieving a 50% improvement in energy efficiency through various energy-saving measures establishes a new baseline for additional savings from renewable energy integration. As a result, holistically, the savings from renewable energy are calculated based on this higher efficiency level, thereby increasing the overall impact on energy reduction and emission savings. However, our model does not account for these overlap effects. It evaluates each credit independently, without considering how improvements in one area can impact savings opportunities in another. Therefore, the model doesn't capture the cumulative benefits of multiple interacting credits. Instead, it shows the savings and maximum effectiveness of each credit individually. This highlights the importance of knowing the actual relative efficacy of each credit.

This subsection provides a detailed assessment for case study 1 across the different categories and credits considered in this model. The considered categories and credits are presented in Table 5.2.

Categories	**Credits**
Location and Transportation	Access to Quality Transit
	Bicycle Facilities
	Electric Vehicle
Sustainable Sites	Heat Island Reduction
Energy and Atmosphere	Enhanced Commissioning
	Optimising Energy Performance

	Advanced Energy Metering
	Renewable Energy
	Building Life Cycle Impact Reduction
Material and Resources	Construction and Demolition Waste Management

Table 5.2 LEED Credit Categories and Credits Considered in the Model Study

5.2.1 Location and Transportation Category Calculations

Beginning with Location and Transportation, this category focuses on aspects concerning the surrounding area, location, and modes of transportation used by staff and occupants. The calculations and models presented here specifically address credits that directly impact CO_2 emissions, which are associated with transportation modes.

Access to quality Transit

This credit encourages the use of multimodal transportation and facilitates access to public transportation options including buses, rails, or ferry terminals. It aims to reduce dependency on personal vehicles by promoting environmentally friendly alternatives.

The assumption for maximum savings under this credit is based on the scenario where all staff members switch from using personal vehicles to public transportation. Assuming that the baseline for personal vehicles is fuel-powered cars. While this transition effectively removes emissions from personal car usage, it introduces emissions from the public transportation modes employed. The savings from this credit is presented in equation Eq 5.1.

Calculation Model:

$$C^S_{AQT} = C^E_{Car} - C^E_{Pub} \quad \text{Eq 5.1}$$

Where,

Carbon savings corresponding to the Access to Quality Transit credit (in tonnes of CO_2) is referred to as C^S_{AQT}. On the right side of the equation, C^E denotes the carbon emissions. Specifically, C^E_{Car} and C^E_{Pub} represent carbon emissions from fuelled cars and public transportation utilisation respectively, both measured in tonnes of CO_2.

C^E_{Car} and C^E_{Pub} are calculated as follows,

$$C^E = \frac{f \times N \times d \times t}{10^6} \quad \text{Eq 5.2}$$

Where,

f, represents the average emissions factor per passenger is defined as the emissions corresponding to the distance travelled by a person using a car or public transportation, measured in grams of CO_2 per passenger-kilometre (gCO_2/pass.km).

N, corresponds to the number of staff. This number is considered to be the number of people travelling to the facility.

d, the average commute distance, which is considered based on national or regional averages which reflect typical commuting patterns in kilometres (km/day)

t, represents the period considered in the exercise, specifically the number of working days in a year (260 days)

Case Study Application

In our model, the emission factor corresponding to cars is set according to the minimum standards established by each country. It reflects the baseline emissions from using personal cars. For case study 1, it is calculated as presented in section 5.3. It is used as 142 gCO_2/pass.km (IEA, 2019; AutoSmart, 2014).

The emission factor per passenger for public transportation varies significantly based on the predominant mode of public transportation available in the area. For instance, in this case study of Saudi Arabia, where the rail infrastructure is minimal, emissions are primarily calculated based on bus usage which is 80 gCO_2/pass.km (EEA, 2021).

Number of staff is equal to 16 as displayed in Table 5.1.

The average commute distance for Saudi Arabia is taken as 54.7 km/day (UNDP, 2022).

Substituting the variables for Case Study I the equation would be as follows:

$C_{car}^{E}= \frac{142 \times 54.7 \times 16 \times 260}{10^6} = 32.31$ tonnes of CO_2

$C_{pub}^{E}= \frac{80 \times 54.7 \times 16 \times 260}{10^6} = 18.2$ tonnes of CO_2

$C_{AQT}^{S} = 32.31 - 18.2 = 14.1$ tonnes of CO_2

Bicycle Facilities

This credit promotes locating near bicycle facilities to encourage the use of bicycles. The carbon savings for the Bicycle Facilities credit are calculated by assuming that all staff members switch from using fuelled cars to bicycles for commuting. Since bicycles do not produce emissions, the carbon savings are equal to the emissions that would have been generated by the use of fuelled cars. This transition effectively eliminates emissions from personal car usage without introducing any additional emissions from cycling. The model does not account for the embodied emissions from bicycles, including those from the production of replacement tyres.

Calculation Model

$$C_{BF}^{S} = C_{car}^{E} \quad \text{Eq 5.3}$$

Where,

Carbon savings corresponding to the Bicycle Facilities credit (in tonnes of CO_2) is designated as C_{BF}^{S}.

Case Study Application

As calculated in the previous credit for Case Study 1, $C_{car}^{E} = 32.31$ tonnes of CO_2

$C_{BF}^{S} = 32.31$ tonnes of CO_2

Electric Vehicle

This credit encourages the adoption of electric vehicles (EVs) by requiring the provision of charging infrastructure at onsite parking facilities. Maximum savings and achieving the full credit score depend on allocating 5% of parking spaces to electric vehicles (EVs). Assuming the number of parking spaces approximately corresponds to staff numbers, ensuring that 5% of these spaces are designated for EVs encourages a corresponding percentage of staff to switch to electric vehicles, thereby optimising the potential savings from this credit. The transition of 5% of the staff to electric vehicles eliminates emissions from their conventional cars. However, this benefit is offset by the additional emissions generated from charging the electric vehicles.

Calculation Model

$$C_{EV}^{S} = C_{car}^{E} - C_{EV}^{E} \quad \text{Eq 5.4}$$

Where,

Carbon savings corresponding to the Electric Vehicle credit (in tonnes of CO_2) is designated as C_{EV}^{S}. Similar to C_{car}^{E}, C_{EV}^{E} correspond to the carbon emissions resulting from charging electric vehicles, taking into account the efficiency of charging (tonnes of CO_2).

C_{EV}^{E} is calculated as follows,

$$C_{EV}^{E} = \frac{E_{EV}^{C} \times \frac{1}{\eta} \times C_{g}^{E} \times d \times N \times t}{10^{6}} \quad \text{Eq 5.5}$$

Where,

E^{c}_{EV}, is the amount of energy consumed by an electric vehicle per kilometre (kWh/km). It is crucial for calculating the energy requirements for commuting distances, typically taken as 0.2 kWh/km/car in our model. (Electric Vehicle Database, 2024)

η, representing the efficiency of charging, this factor accounts for the losses involved in charging EVs, important for estimating the actual energy used from the grid, considered as 89.4% in our calculations (Sears, et al., 2014), aligning with Level 2 charging capacity requirements.

C^{E}_{g} This denotes the carbon emissions from the grid. This measures the CO_2 emissions per kWh of electricity generated by the grid. It varies by country and is essential for calculating the impact of emissions from consuming grid electricity. Measured by gCO_2/kWh.

Case Study Calculations

To accommodate the practical implementation of electric vehicle facilities, we apply the figure of 5% to the total number of parking spaces, rounding the result to the nearest whole number to determine the necessary number of EV charging stations.

The adjusted number of staff in the equation represents the 5% of the workforce expected to utilise electric vehicles, thus accounting for the corresponding number of charging stations required= 5% × 16 = 0.8 ≈ 1

C^{E}_{car}= = 2.01 tonnes of CO_2

C^{E}_{g} in this case study in Saudi Arabia is 569 gCO_2/kWh

Substituting the variables for case study 1 in Eq 5.4 and Eq 5.5,

$$C_{EV}^{E} = \frac{0.2 \times \frac{1}{89.4\%} \times 54.7 \times 569 \times 1 \times 260}{10^6} = 1.81 \text{ tonnes of } CO_2$$

$$C_{EV}^{S} = 2.01 - 1.81 = 0.21 \text{ tonnes of } CO_2$$

5.2.2 Sustainable Sites Category Calculations

This category is dedicated to integrating sustainable land use and development practices. While many credits within this category focus primarily on land preservation and habitat, the Heat Island Reduction credit impacts emission savings by boosting energy efficiency through architectural and material choices.

Heat Island Reduction

The Heat Island Reduction credit encourages mitigation the urban heat island effect by adopting measures that decrease heat absorption and enhance the thermal characteristics of building exteriors and adjacent surfaces. This is achieved through the application of reflective materials on roofs and other horizontal surfaces, enabling buildings to reflect more sunlight and absorb less heat. This reduction in heat absorption naturally decreases cooling requirements, thereby lowering energy consumption and enhancing overall energy efficiency.

Calculation Model:

$$C_{HIR}^{S} = \frac{P_c \times 8760 \times C_g^E \times S_{\%}}{10^6} \qquad \text{Eq 5.6}$$

Where,

Carbon savings corresponding to the Heat Island Reduction credit (in tonnes of CO_2) is designated as C_{HIR}^{S}.

$S_{\%}$, denotes the energy efficiency improvement resulting from this practice (%).

P_c, represents the cooling power in a data centre. Cooling power refers to the amount of electrical power required to operate the cooling systems that maintain the optimal operating temperature and environment for the data centre's IT equipment (kW).

Cooling Power (P_c) is calculated as follows,

$$P_c = [(PUE \times P_{IT}) - P_{IT}] \times 80\% \qquad \text{Eq 5.7}$$

Where,

PUE, denotes the facility Power Usage Effectiveness, which indicates the facility overhead for running the server (to cover cooling, power infrastructure, etc.).

P_{IT}, refers to the amount of electrical power consumed by the information technology equipment within a data centre. This includes servers, storage devices, networking equipment, and other computing infrastructure necessary for data processing and storage.

The 80% represents the proportion of the cooling system's contribution to the overhead power in a typical data centre. This figure is derived from white paper data, where Figure 5.1 provided the basis for calculating the chart presented in Figure 5.2, which specifically presents breakdown of facility load in data centre (Schneider, 2011). The estimated value of 0.8, rounded for practical application, accurately reflects the significant energy demand attributed to cooling systems within the data centre environment.

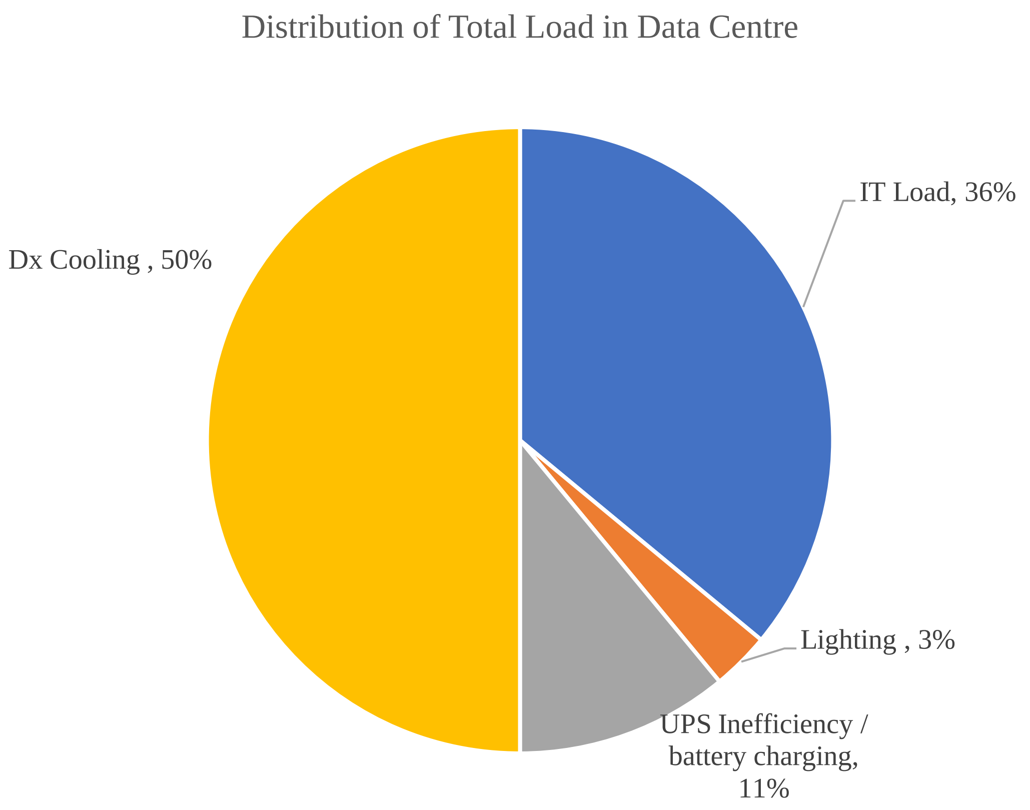

Figure 5.1 Detailed Breakdown of Total Load in Data Centre (Schneider, 2011)

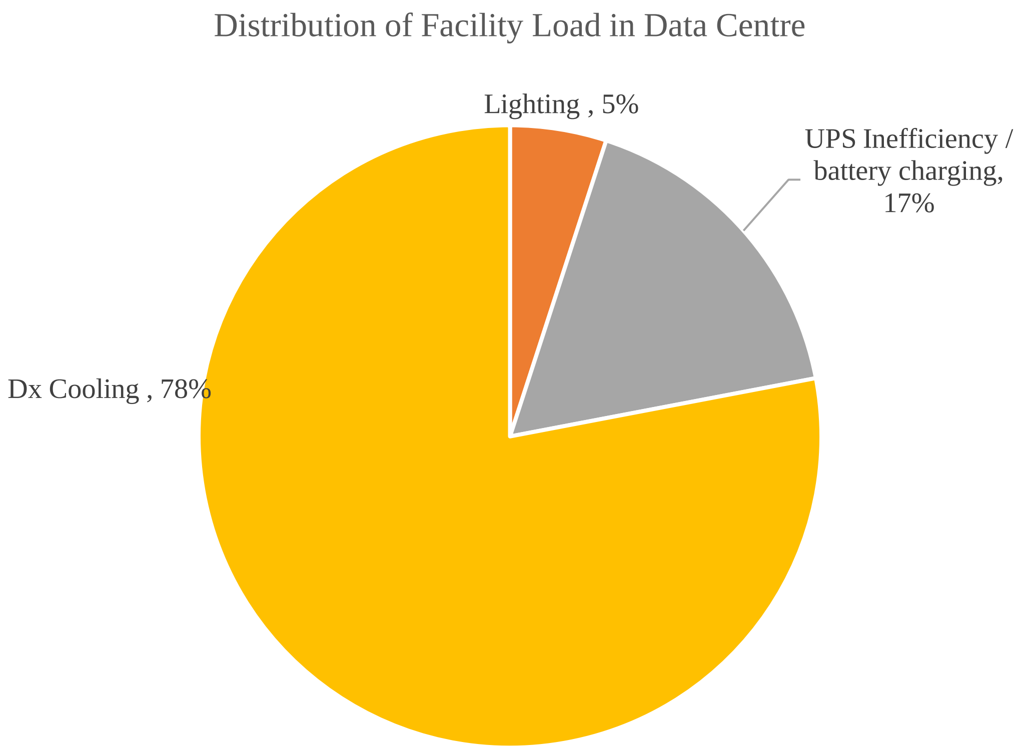

Figure 5.2 Detailed Breakdown of Facility Load In Data Centre

The effectiveness of heat island reduction strategies, such as cool roofs, is heavily influenced by variables including ambient temperature, daily temperature fluctuations, solar radiation intensity, and the reflective and emissive properties of the materials used. As a result, the percentage savings can vary significantly between different climates. For example, savings might be around 2% in London (Virk, et al., 2015) but could reach up to 24% in hotter climates (Algarni, 2018). Variability within a single country can also be significant, influenced by local factors such as climate, dust accumulation, and material properties (Algarni, 2018).

In the context of data centres, which require intensive cooling systems due to their high heat load, the typical reductions in heat absorption differ from those in other types of buildings. Measures like cool roofs or increased albedo are not as effective in data centres as they are in other buildings. This difference arises because data centres have fundamentally different operational and cooling requirements compared to residential or office buildings. Consequently, savings observed in residential settings cannot be directly compared with those achievable in data centres.

For instance, research indicates that the maximum savings in residential buildings in mild climates, such as Riyadh, can reach up to 24%. However, when applying these figures to data centres, adjustments must be made to reflect their unique energy usage profiles. Table 5.3 presents parameters and savings derived from a study on a residential building in Riyadh, which yielded an energy reduction of 20.8 watts per square meter. It displays the cooling consumption with the relative reduction seen with the cool roofs' usage.

Cooling consumption Watt/m^2 BAU	**Cooling consumption Watt/m^2 with cool roof**	**Cooling Reduction Watt/m^2**	**% Reduction**

86.1	65.3	***20.8***	24%

Table 5.3 Parameters and Cooling Load Reductions in Residential Building, Riyadh (Algarni, 2018)

The cooling reduction resulted from cool roofs is highlight in the table above. Assuming an equivalent load reduction applicable to data centres, when applying this to the typical cooling load of a data centre, the calculation yields a savings of 8% as per the calculations below.

Cooling Consumption (BAU) for data centre = 244.4 Watt/m^2

Cooling Reduction = 20.8 Watt / m^2

$$S_{\%} = \frac{20.8}{244.4} = 8\%$$

$S_{\%}$ used is 8%. This percentage is based on calculations and current studies. There is a need for more targeted research due to the limitation of data centre-specific impact assessments. However, this figure remains an assumption and estimate, influenced by the limited availability of specific studies focusing on data centres.

Case Study Calculations

PUE and P_{IT} for case study 1 are 2.3 and 500 kW respectively, as shown in Table 5.1

Substituting variables corresponding to Case Study 1 in Eq 5.6 and Eq 5.7,

$$P_C = [(500 \times 2.3) - 500\,] \times 80\% = 520 \text{ kW}$$

$$C_{HIR}^{S} = \frac{520 \times 0.08 \times 8760 \times 569}{10^6} = 207.35 \text{ tonnes of } CO_2$$

5.2.3 Energy and Atmosphere Category Calculations

This category within LEED focuses on optimising energy performance and enhancing the use of renewable and green energy sources. This category is crucial for reducing a data centre's operational energy demand, minimising reliance on non-renewable energy, and thereby reducing associated greenhouse gas emissions.

All credits in this category have been considered in the model, as they are recognised for their potential to save. However, the Demand Response/Grid Harmonisation credit is not included in this analysis because it primarily contributes to savings in power plant capacity and overall emissions reduction rather than direct energy savings or emissions reductions within the data centre itself. Demand response programmes are designed to reduce or shift electricity usage during peak demand periods, which helps to stabilise the grid, defer the need for additional power plant capacity, and lower overall emissions by reducing reliance on less efficient, higher-emission power plants. While these benefits are significant for the electrical grid and the environment, they do not directly reflect the energy consumption or emissions metrics specific to the data centre's operations that contribute to our model consideration.

The credits in this category achieve emission savings through two primary mechanisms: energy efficiency and the utilisation of green power. Energy efficiency credits focus on reducing energy consumption through improved practices and technologies, while green power credits emphasise the adoption of renewable energy sources to lower the carbon intensity of the energy used.

The calculation for energy efficiency related credits follows a similar methodology, with the variation lying in the specific energy savings percentages attributed to each practice. This involves quantifying the reduction in energy consumption as a result of implementing various energy efficiency measures.

In contrast, the savings from the utilisation of green power are based on the percentage of renewable energy used and the corresponding reduction in dependency on fossil fuels. This involves calculating the decrease in emissions by substituting conventional energy sources with renewable ones, thereby lowering the overall carbon footprint of the data centre.

Enhanced Commissioning

This credit is designed to ensure that the design, construction, and eventual operation of a project meet the owner's specific requirements for energy, water, indoor environmental quality, and durability. The primary goal is to optimise system performance and avoid inefficiencies that can arise from missing crucial commissioning steps. Proper commissioning ensures that building systems are installed, calibrated, and performed according to the owner's operational needs, thus supporting sustainability and efficiency from the beginning.

Commissioning is a standard practice employed in data centre facilities to ensure that all systems and components operate according to design specifications and meet performance criteria. It involves a systematic approach to testing, verifying, and documenting the functionality of critical infrastructure, including power distribution, cooling systems, and security measures. There are different ranges of savings depending on the commissioning process employed. Although there is no single study specific to data centres that provides comprehensive savings data, several studies highlight the importance and potential savings from commissioning practices. For instance, non-retrofitted buildings that have the commissioning process applied show significant savings: chilled water savings averaged 28%, heating savings averaged 54%, and electrical savings ranged from 2% to 20% (Claridge, et al., 2000).

Calculation Model

Eq 5.8 is used for all credits related to energy efficiency savings with the difference in savings constant. The savings percentage is linked directly to the practice used.

$$C_{EE}^{S} = \frac{P_T \times S_{\%} \times 8760 \times C_g^E}{10^6} \qquad \text{Eq 5.8}$$

Where,

Carbon savings from energy efficiency practices is denoted by C_{EE}^{S}.

P_T, refers to the total power. the combined electrical power required to operate all aspects of the data centre. This includes the power consumed by the IT equipment, cooling systems, power distribution, and other supporting infrastructure. Measured by kilowatts (kW).

P_T is calculated as follows,

$$P_T = PUE \times P_{IT} \qquad \text{Eq 5.9}$$

Savings ($S_{\%}$) from commissioning credit is assumed to be 20% savings of electricity (Claridge, et al., 2000).

Case Study Calculations:

Substituting variables for Case Study 1 in Eq 5.8 and Eq 5.9:

$P_T = 2.3 \times 500 = 1150\ kW$

This yields savings from Enhanced commissioning to be,

$C_{EC}^{S} = \frac{1150 \times 20\% \times 8760 \times 569}{10^6} = 1146.42$ tonnes of CO_2

<u>Advanced Energy Metering</u>

The Advanced Energy Metering credit aims to support energy management and identify opportunities for additional energy savings by tracking building-level and system-level energy use. This credit is particularly important for data centre managers and operators, as it enables accurate measurement and monitoring of energy consumption, which is essential for optimising the energy efficiency of their facilities. Typical energy savings achieved through energy metering range from 5% to 15% (NSW Government, 2024).

Calculation Model:

Eq 5.8 is applied to calculate savings from advanced metering where savings ($S_{\%}$) is taken as 15% from advanced energy metering credit in our model accounting for the maximum opportunities.

Case Study Calculations:

Substituting variables for Case Study 1:

Savings from Advanced Metering credit is,

$$C_{AM}^{S} = \frac{1150 \times 15\% \times 8760 \times 569}{10^6} = 859.82 \text{ tonnes of } CO_2$$

Optimise Energy Performance

The Optimising Energy Performance credit aims to achieve increasing levels of energy performance beyond the prerequisite standard. The goal is to reduce environmental and economic harms associated with excessive energy use and greenhouse gas emissions, which disproportionately impact frontline communities. This credit encourages significant improvements in energy efficiency, rewarding projects with higher points for greater efficiency achievements.

The points awarded for this credit vary based on the level of energy efficiency attained. Higher efficiency results in more points. For instance, achieving a 50% improvement in energy efficiency earns 18 points. Continuous updates to the standards and point assessments are ongoing. For projects registered after March of the current year (2024), points will be provided based on direct improvements to greenhouse gas emissions and energy efficiency.

Calculation Model

Similarly, Eq 5.8 is applied for this credit calculating the savings associated with it.

In this credit, savings ($S_{\%}$) is taken as 50% in the model.

Case Study Calculations

Substituting variables for Case Study 1:

Savings from Optimise Energy Performance credit,

$$C_{OP}^{S} = \frac{1150 \times 50\% \times 8760 \times 569}{10^6} = 2{,}866 \text{ tonnes of } CO_2$$

<u>Renewable Energy</u>

The Renewable Energy credit in the LEED framework promotes the use of renewable energy sources to reduce dependence on non-renewable energy and lower greenhouse gas emissions. This credit awards points based on the percentage of total site energy use derived from renewable sources, including on-site generation, new off-site renewable energy, and off-site renewable energy procurement.

As mentioned before, the savings associated with this credit are dependent on the percentage of renewable energy used. The greater the proportion of renewable energy, the more significant the potential emissions savings, aligning with the sustainability goals of the data centre.

Wind energy is selected as it has the lowest intensity among all renewable energies, considering the life cycle energy intensity of new renewable energy implementations.

Calculation Model

$$C_{RE}^{S} = \frac{(P_T \times 8760 \ \times RE_{\%}) \times (\ C_g^E - C_{RE}^E)}{10^6} \qquad \text{Eq 5.10}$$

Where,

Carbon savings from Renewable Energy credit is designated by C_{RE}^{S}.

$RE_{\%}$ the percentage of total site energy use that comes from renewable energy sources. For the highest savings and maximum points, we consider this to be 100%.

C_{RE}^{E} denotes the carbon intensity of the renewable energy utilised, measured in grams of CO2 per kilowatt-hour (gCO_2/kWh). This variable represents the weighted average carbon emissions associated with all renewable energy sources included in the analysis. Specifically, for our model, we assume wind energy as the sole renewable source, with a carbon intensity of 11 gCO_2/kWh (EERE, 2023).

Case Study Calculations

Substituting variables and constant in Eq 5.10 for case study 1,

$$C_{RE}^{S} = \frac{(1150 \times 8760 \times 100\%) \times (569 - (11 \times 100\%))}{10^6} = 5621.29 \text{ tonnes of } CO_2$$

5.2.4 Material and Resources Category Calculations

The Material and Resources category in the LEED framework focuses on minimising the environmental impact of materials used in construction and operations. This includes promoting the use of sustainable building materials, reducing waste, and encouraging efficient waste management practices. The credits in this category aim to reduce the overall carbon footprint and resource consumption associated with building construction and operation.

The credits included in the model are Building Life Cycle Impact Reduction and Construction and Demolition Waste Management, which relate to scope 3 emissions reduction. Other credits, such as Sourcing of Raw Materials and Environmental Product Declarations, are not included as they are more focused on declaration and sourcing rather than direct practices for reducing emissions.

<u>Building Life Cycle Impact Reduction</u>

This credit is included because it focuses on minimising the life cycle impacts of building materials and promoting sustainable construction practices, directly contributing to scope 3 emissions reduction. It mainly focuses on the building enclosure.

Calculation Model

$$C_{LCI}^{S} = \frac{A \times C_{LCA}^{E} \times R_{\%}}{L_{DC} \times 1000} \qquad \text{Eq 5.11}$$

Where,

Emission savings from Building life cycle impact reduction is denoted by C_{LCI}^{S}.

A is area of facility expressed in m^2

C_{LCA}^{E} is the life cycle assessment (LCA) emission rate, based on RIBA analysis for business-as-usual office buildings, due to the lack of specific data for data centres (RIBA, 2021). It is taken as 1400 $kgCO_2/m^2$.

$R_{\%}$ the reduction in CO_2 equivalence, as specified by LEED requirements.

L_{DC} life of data centre is assumed to be 20 years.

Case Study Calculations

The area of Case Study 1 is 2,250 m^2 as displayed in Table 5.1

Substituting the variables and constants for case study 1,

$C_{LCI}^{S} = \frac{2250 \times 1400 \times 20\%}{20 \times 1000}$ = 31.5 tonnes of CO_2

<u>Construction and Demolition Waste Management</u>

The Construction and Demolition Waste Management credit focuses on diverting construction and demolition debris from landfills by recycling and reusing materials. This credit encourages efficient waste management practices to minimise the environmental impact of construction activities. In our model, it is assumed that recycling is implemented to achieve the maximum potential savings in carbon emissions.

Calculation Model

$$C_{CDW}^{S} = \frac{A \times Q_{C}^{W} \times C_{REC}^{S}}{L_{DC} \times 10^{6}} \qquad \text{Eq 5.12}$$

Where,

Emissions Savings from construction demolition waste management is denoted by C_{CDW}^{S} (tonnes of CO_2).

Q_C^W The amount of construction waste generated per square meter of the facility, expressed in kilograms. It is taken as 120 kg waste / m^2 (Lltas, 2011).

C_{REC}^S The reduction in carbon emissions achieved by recycling 1 tonne of construction waste, based on relevant studies. Taken as 100 $kgCO_2$/tonnes of waste (Coyne, et al., 2023).

Case Study Calculations

Substituting variables and constants for case study 1,

$$C_{CDW}^S = \frac{2250 \times 120 \times 100}{20 \times 10^6} = 1.35 \text{ tonnes of } CO_2$$

The next section displays the summary of parameters used in all case studies and corresponding results for each.

5.3 Summary of Equations and Parameters and Environmental Savings Results Across All Case Studies

This section presents a summary of the variables and assumptions used in the environmental model. It also summarises and reflects on the equations applied. Finally, it shows the results of the environmental savings across the credits applied to the five different case studies.

5.3.1 Variables and Assumptions used in the model

The subsection presents all the variables and assumptions used to compute the environmental savings of different credits, applied across case studies of varying types, sizes, and locations.

Variables are influenced by either the facility or the data centre's location.

Data Centre – Specific Parameters

- IT Load: The data centre load consumed or dedicated to IT equipment, such as servers, storage equipment, and communication switches and routers. This load is measured in kilowatts (kW).
- Number of Staff: The number of employees at a data centre can vary significantly, typically ranging from a few dozen to several hundreds, depending on the size and complexity of the centre.
- PUE: is the ratio of total facility energy to IT equipment energy.
- Area: The space of the building used to house computing equipment and facilities, measured in square metres (m^2). This variable depends on the type of data centre, with hyperscale data centres generally having larger areas compared to colocation and enterprise data centres.

Location – Specific Variables

- Grid Intensity: This measures the CO_2 emissions per kWh of electricity generated by the grid. It varies by country and is essential for calculating the emissions impact of consuming grid electricity. Each country has a different composition for electricity generation depending on the availability of renewables, economic factors, and regulatory applicability.

Based on our case studies, Saudi Arabia has the highest grid intensity (Climate Transparency, 2022), followed by Ireland (SEAi, 2022), then Belgium, and finally Sweden, which has the lowest due to its extensive use of renewable energy sources (EMBER, 2024).

- Emissions per passenger per km (Car): This variable is set according to the minimum standards established by each country. It reflects the baseline emissions from using personal cars based on typical fuel efficiencies and usage patterns prevalent in the region. Expressed in gCO_2/passenger.km.

  For Saudi Arabia, values are calculated based on the targets set by the Saudi CAFE standard, which aims to lower fuel economy to 19 km per litre by 2025 (IEA, 2019). The emissions are calculated using emission factor for diesel emissions as 2.7 kg CO2/ Litre (AutoSmart, 2014):

$$\text{Car Average Emission}_{\text{Saudi Arabia}} = \frac{2.7}{19} = 0.142 \text{ kgCO}_2\text{/passenger car.km}$$

$$= 142 \text{ gCO}_2\text{/passenger car.km}$$

  For Europe, emissions are assumed as stated for regulatory standards, which are approximately 95 gCO_2/km (IEA, 2021).

- Emissions per Passenger (Public Transportation): This metric varies significantly based on the predominant mode of public transportation available in the area. For instance, in Saudi Arabia, where the rail infrastructure is minimal, emissions are primarily assumed to be from bus usage. In Europe, where the rail network is extensive and heavily utilised, rail emissions are a major consideration. This metric is sourced from research comparisons conducted by the EU (EEA, 2021).Expressed in gCO_2/passenger.km.

- Distance: The average daily commute distance is considered based on national or regional averages, reflecting typical commuting patterns (UNDP, 2022) (EU Commission, 2022b). Expressed in kilometres (km).

Variables and Assumptions are displayed in Table 5.4 and Table 5.5. Table 5.4 presents the variable directly related to the case studies and data centres' characteristics.

Data Centre - Related Variables					
Factors	**Case Study 1**	**Case Study 2**	**Case Study 3**	**Case Study 4**	**Case Study 5**
Location	Saudi Arabia	Saudi Arabia	Belgium	Ireland	Sweden
IT Load (kW)	500	600	1500	300	100,000
Number of Staff	16	15	12	7	150
PUE	2.3	2.2	1.7	1.9	1.2
Area	2,250	2,700	6,750	1,350	450,000

Table 5.4 Data Centre-Related Variables Used in the Model

Location-Based Variables					
Factors	**Case Study 1**	**Case Study 2**	**Case Study 3**	**Case Study 4**	**Case Study 5**
Grid Intensity (gCO2/kWh)	569	569	138	259	41
Car Emissions (gCO2/pass.km)	142	142	95	95	95
Public Transportation Emission (gCO2/pass.km)	80	80	33	33	33
Average Commute Distance (km)	54.7	54.7	24	26	21

Table 5.5 Location-Based Variables Used in the Model

Assumptions used in the equations:

Assumptions are defined in Section 5.2.

A summary of the assumptions used are displayed in Table 5.6.

Assumed factors used in the equations		
Assumed Factors	**Unit**	**Value**
Electric Vehicle energy consumption	kW/km/car	0.2
Electricity Vehicle Charging Efficiency	%	89.4
Enhanced Commissioning Savings	%	20
Heat Island Reduction Savings	%	8
Optimise Energy Savings	%	50
Advanced Metering Savings	%	15

Life Cycle Credit Savings	%	20
Renewable Energy Share	%	100
Workdays	days	260
Construction Phase Emission	gCO_2/m^2	1,400
Wind Intensity	gCO_2/kWh	11
Amount of Waste during Construction	Kg Waste/ m^2	120
Construction Waste Recycling Savings	Kg CO_2 / tonnes of Waste	100
Data Centre Age	Years	20
Cooling Composition	%	80%

Table 5.6 Assumed Factors Used in the Model

5.3.2 Results Summary

Applying the model calculations to all case studies, Table 5.7 displays the CO_2 savings for each case.

CO_2 Potential Opportunity savings in (tonnes of CO_2)					
LEED Environmental Credits	**Case Study 1 Savings**	**Case Study 2 Savings**	**Case Study 3 Savings**	**Case Study 4 Savings**	**Case Study 5 Savings**
Access to Quality Transit	14.11	13.23	4.64	2.93	50.78
Bicycle Facilities	32.31	30.29	7.11	4.50	77.81
Electric Vehicles	0.21	0.21	0.4	0.25	3.75
Heat Island Reduction	207.35	229.68	81.24	39.21	459.72
Enhanced Commissioning	1,146.42	1,315.89	616.53	258.65	8,619.84
Optimise Energy Performance	2,866.05	3,289.73	1,541.32	646.62	21,549.6

Advanced Energy Metering	859.82	986.92	462.40	193.99	6,464.88
Renewable Energy	5,621.29	6,452.27	2,836.93	1,238.31	31,536
Building Life-Cycle Impact Reduction	31.5	37.8	94.5	18.9	6,300
Construction and Demolition Waste Management	1.35	1.62	4.05	0.81	270

Table 5.7 Maximum Opportunity Calculated Results Across All Cases

The next subsection provides an analysis of the data and calculations, comparing the results to the LEED score reflections.

5.4 Maximum Opportunity across the environmental credits in LEED for different data centre case studies

This section presents the analysis of outcomes derived from applying the mathematical equations to five case studies. It highlights the maximum potential for CO_2 savings achievable through various LEED environmental credits. It provides a quantitative assessment of the environmental benefits that can be realised within the LEED certification framework.

Emissions are analysed from multiple perspectives, each crucial for informed decision-making and understanding the impact of different factors. This section demonstrates the multifaceted nature of CO_2 emissions analysis by showing the actual total savings opportunity of credits in subsection 5.4.1 and the tonnes of CO_2 savings per IT load in section 5.4.2. The section ties up by presenting percentage of actual savings across the different environmental credits in Section 5.4.3.

5.4.1 Absolute CO_2 Savings from Environmental Credits Across Five Case Studies

The section discusses the maximum CO_2 saving opportunities from various LEED credits across the five case studies. Figure 5.3 presents the CO_2 savings in tonnes, illustrating the impact of different environmental credits across these case studies.

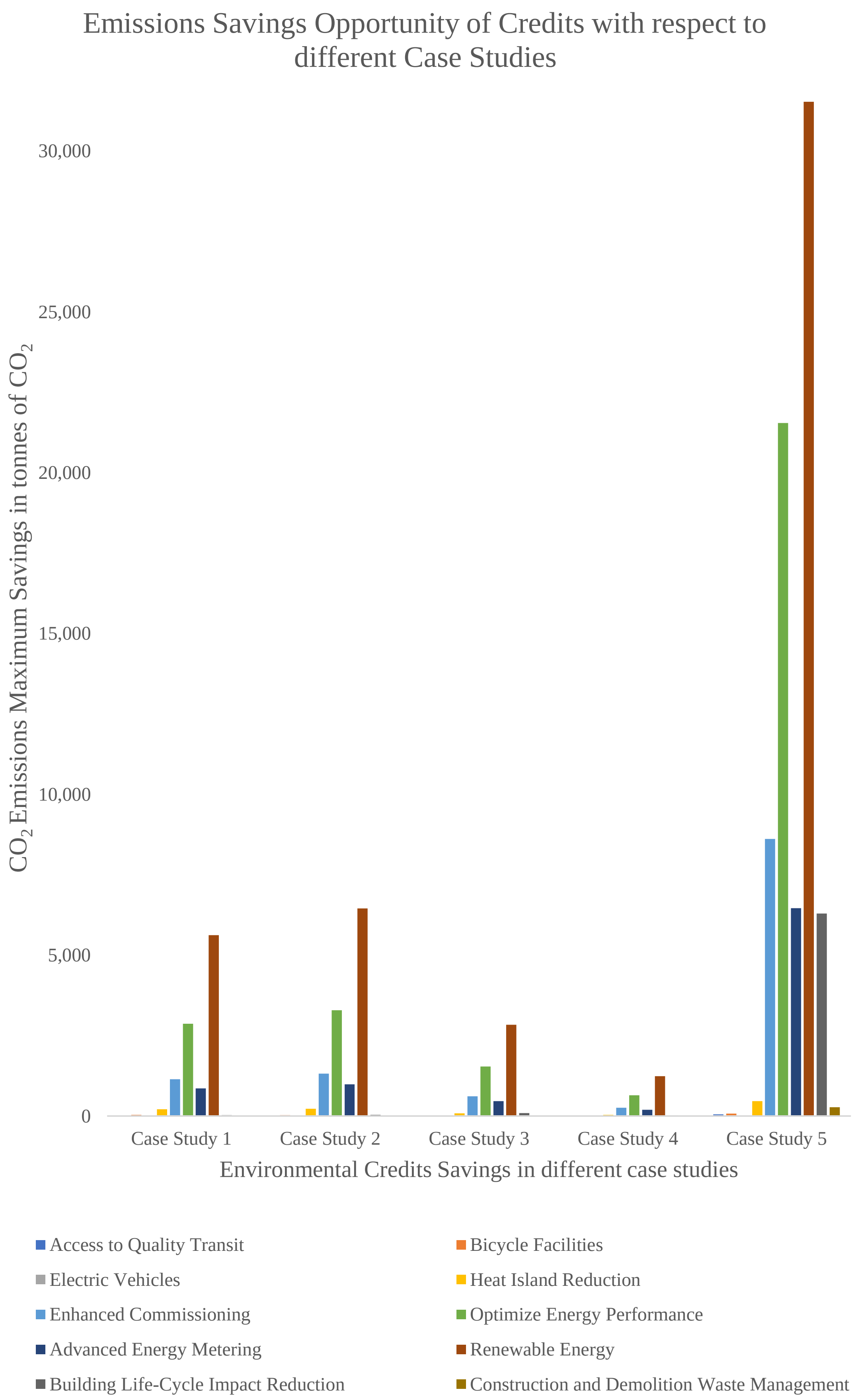

Figure 5.3 Maximum Opportunity Savings Across Different Credits in The LEED Framework

The bar graph represents the significant variance in CO_2 savings across different data centres, highlighting the varying impact of specific LEED credits. Results show that case study 5, which represents a hyperscale data centre, reported a significant measurable CO_2 savings. Some credits show negligible savings, including those in the location and transportation category and the material and resources category. The building life cycle impact reduction credit, while negligible in most case studies, shows more significant savings in case study 5. This increase in savings is due to the larger area and greater impact of the building. Additionally, the existing green power in the grid results in lower savings from renewable energies. This lowers the impact of scope 2 emissions. Consequently, the focus shifts to the importance of scope 3 savings. The hyperscale shows the most considerable savings potential. Given the substantial energy consumption and vast areas of hyperscalers, the magnitude of savings reflects the scale of their operations.

Such findings gain particular importance in light of the anticipated expansion of the hyperscale data centre market, which is expected to grow from USD 80.16 billion in 2022 to an estimated USD 935.3 billion by 2032 (Precedence Research, 2023). As this market sector expands, the potential increases for implementing more efficient practices, which can yield significant environmental savings.

A consistent trend in CO_2 savings is evident across the five case studies, with the most significant savings almost uniformly seen in Scope 2 emissions related to purchased electricity. Credits that focus on Optimising Energy Performance and Renewable Energy stand out as significant contributors to emissions reductions, reflecting the high electricity demand of data centres.

Following energy-related credits, savings are seen in credits related to the construction phase. Transportation-related credits, such as Access to Quality Transit and Bicycle Facilities, show the least CO_2 savings. This trend is consistent with the generally low number of staff at data centres, which reduces the relative impact of transportation initiatives on overall emissions.

The following subsection presents the normalised CO_2 savings by IT load.

5.4.2 CO_2 Savings per Unit of IT Load Across Environmental Credits

The subsection presents the normalised savings opportunity. The CO_2 savings per IT load are shown in Figure 5.4. The results highlight how normalising by IT load reveals the impact of factors such as grid intensity on the environmental performance of data centres. This comparative approach illustrates the influence of the local energy grid on sustainability outcomes.

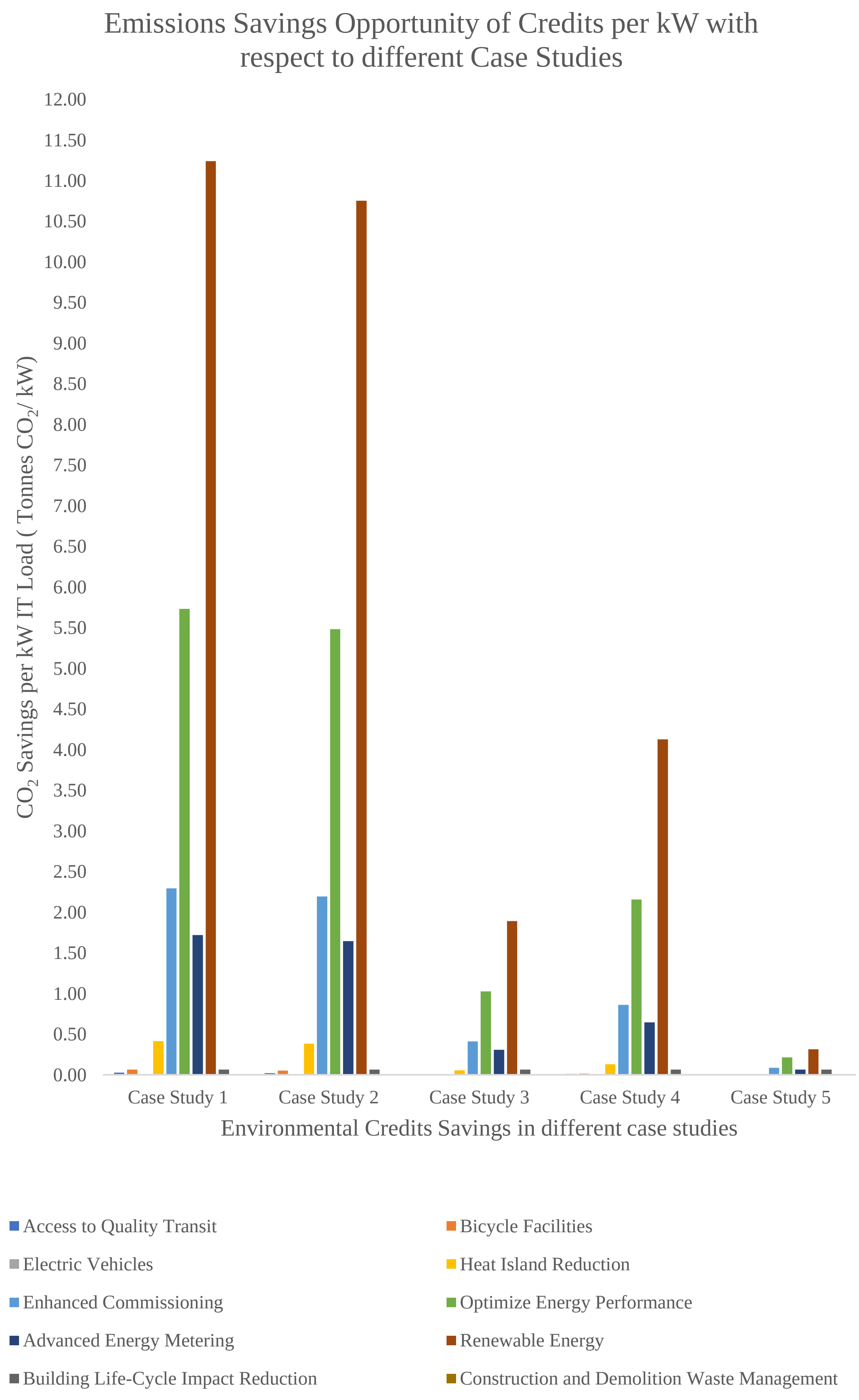

Figure 5.4 Normalised Maximum CO_2 Emission Savings per Credit Across Five Case Studies

Analysing the figure, we observe that data centres linked to grids with a higher intensity of non-renewable energy present substantial opportunities for CO_2 savings through LEED credits. This evaluation is particularly noticeable in Saudi Arabia, where Case Studies 1 and 2 demonstrate the most significant potential for savings. Moreover, due to their heavy reliance on fossil fuels, adopting renewable energy in these data centres leads to notable CO_2 reductions, achieving 11.24 tonnes per kW. This figure is markedly higher than the savings from Optimising Energy Performance, which achieves 5.73 tonnes per kW.

Conversely, the scenario in Sweden presents a stark contrast due to its grid's high proportion of renewable energy. Here, additional adoption of renewable energy in data centres yields only 0.31 tonnes per kW, a slight increase compared to the savings from Optimise Energy Performance, which is 0.21 tonnes per kW. The minimal difference between these figures highlights the already clean state of Sweden's energy grid. It indicates that focusing solely on renewable energy credits yields diminishing returns in such regions. Instead, the emphasis shifts towards enhancing energy efficiency, improving construction materials, and as well addressing scope 3 emissions to drive further reductions.

This analysis highlights the critical role of the local energy grid's composition in determining the effectiveness of LEED credits for CO_2 reduction. While regions like Saudi Arabia can benefit significantly from renewable energy credits, in places like Sweden, where the grid's carbon intensity is already low, advancing sustainability requires varied strategies.

As we proceed, the following subsection offers a comparative analysis of the actual proportion of CO_2 savings attributed to various LEED credits, showing a comprehensive picture of the real-world impact of these sustainability measures.

5.4.3 Comparative Analysis of CO_2 Savings Across LEED Credits

Building on insights from Sections 5.4.1 and 5.4.2, which explored how various factors influence CO_2 savings, it is evident that responses to sustainability practices vary across case studies. This subsection examines the impact of individual LEED credits by presenting each contribution's savings as a proportion. Figure 5.5 illustrates the proportion of savings attributed to different LEED credits across the case studies, with each line representing a specific credit.

The figure illustrates that the Renewable Energy credit accounts for a substantial portion of savings, contributing between 41% and 52%. While also significant, in the second place comes the Optimizing Energy Performance credit varying between 26% and 28%.

Conversely, transportation-related credits have a minimal impact, contributing no more than 1% to the total savings. This contrast highlights the lesser role of transportation-related improvements in the overall CO_2 savings within data centres.

Table 5.8 consolidates the data illustrated in Figure 5.5, presenting the ranking of each LEED credit by the impact of the savings in descending order.

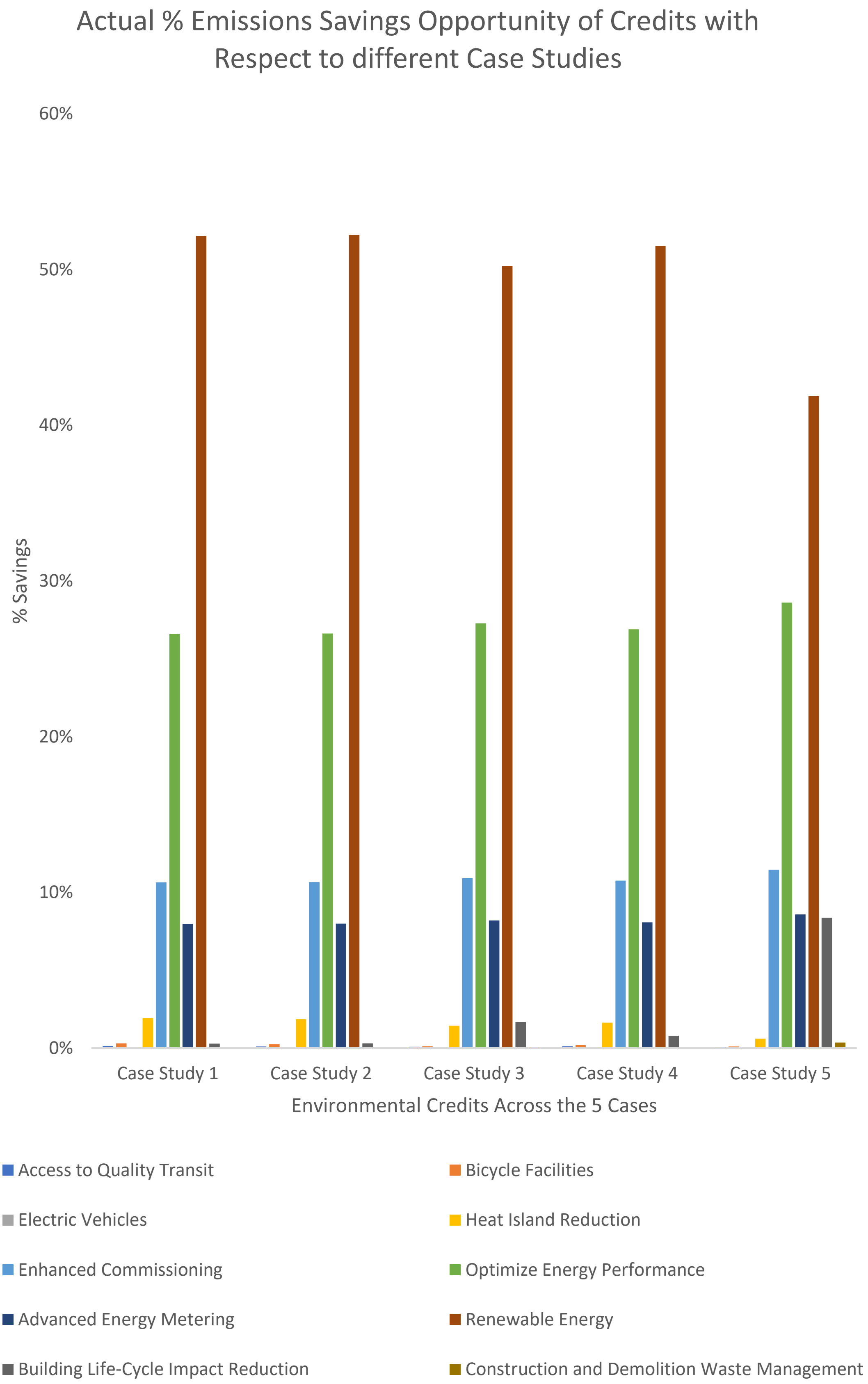

Figure 5.5 Proportional Contribution of Each Credit to Total

Descending Order of LEED Credits by Savings Impact (Case Study 1)	**Descending Order of LEED Credits by Savings Impact (Case Study 2)**	**Descending Order of LEED Credits by Savings Impact (Case Study 3)**	**Descending Order of LEED Credits by Savings Impact (Case Study 4)**	**Descending Order of LEED Credits by Savings Impact (Case Study 5)**
Renewable Energy	Renewable Energy	Renewable Energy	Renewable Energy	Renewable Energy
Optimise Energy Performance	Optimise Energy Performance	Optimise Energy Performance	Optimise Energy Performance	Optimise Energy Performance
Enhanced Commissioning	Enhanced Commissioning	Enhanced Commissioning	Enhanced Commissioning	Enhanced Commissioning
Advanced Energy Metering	Advanced Energy Metering	Advanced Energy Metering	Advanced Energy Metering	Advanced Energy Metering
Heat Island Reduction	Heat Island Reduction	Heat Island Reduction	Heat Island Reduction	Building Lifecycle Impact Reduction

Building Lifecycle Impact Reduction	Building Lifecycle Impact Reduction	Building Lifecycle Impact Reduction	Building Lifecycle Impact Reduction	Heat Island Reduction
Bicycle Facilities	Bicycle Facilities	Bicycle Facilities	Bicycle Facilities	Construction and Demolition Waste Management
Access to Quality Transit	Access to Quality Transit	Access to Quality Transit	Access to Quality Transit	Bicycle Facilities
Construction and Demolition Waste Management	Construction and Demolition Waste Management	Construction and Demolition Waste Management	Construction and Demolition Waste Management	Access to Quality Transit
Electric Vehicles	Electric Vehicles	Electric Vehicles	Electric Vehicles	Electric Vehicles

Table 5.8 LEED Credits Ranked by Impact on CO_2 Savings

The results show that Cases 1 through 4 have a consistent pattern of savings across the credits, while Case 5 shows a different trend, emphasising the need to focus more on construction-phase impacts as operations scale up in hyperscale data centres. This highlights that there isn't one framework that works for all data centres due to several factors. The factors include facility and location characteristics.

It's important to highlight that these figures represent only the savings from LEED credits. They do not include scope 3 emissions from IT and server equipment, a significant emissions source not accounted for in this assessment.

5.4.4 Average Impact Savings Proportions

This section concludes with Table 5.9, which displays the average impact of savings for each credit, underlining the significance and opportunities for data centres to improve sustainability through targeted LEED credits. The averages used are the ones corresponding to the normalised savings.

LEED Environmental Credits	**Averages**
Access to Quality Transit	0.12%
Bicycle Facilities	0.25%
Electric Vehicles	0.0035%
Heat Island Reduction	1.80%
Enhanced Commissioning	10.69%
Optimise Energy Performance	26.72%
Advanced Energy Metering	8.02%
Renewable Energy	51.80%
Building Lifecycle Impact Reduction	0.58%
Construction and Demolition Waste Management	0.02%

Table 5.9 Corresponding Impact Savings of LEED Credits

Based on the actual impact savings of each LEED credit, the following section thoroughly compares with the allocated score proportions. This analysis reveals the alignment or potential discrepancies between LEED credits expected and realised benefits.

5.5 Analysis of Allocated Scores in LEED Compared to Actual Savings

This section offers a comparative analysis that provides valuable insights into how effectively the LEED certification system reflects the actual environmental impacts observed in various data centres. First, it provides a broader perspective by comparing the actual savings from environmental credits with the LEED scoring proportions out of the total possible points 110. This comparison offers an understanding of the overall effectiveness of the LEED system. Subsequently, the analysis focuses on the specific environmental credits, comparing the actual savings to the LEED scoring proportions when considering only the 46 points directly associated with these credits. The underlying assumption is that the total savings are achieved if the corresponding LEED credit score is fully attained.

This section is crucial as it helps stakeholders understand that certain credits may appear more impactful than they are, based on LEED scoring, due to significant discrepancies. It assists operators to prioritise efforts and resources on credits that deliver substantial environmental savings. Moreover, it directs policymakers and regulators to refine green building standards and incentives based on actual environmental performance rather than solely on LEED scores.

5.5.1 Comprehensive Perspective: Total LEED Points and Environmental Savings

Gaining a higher certification level in LEED aims to enhance a building's environmental profile and achieve a higher green certification. After calculating the savings from LEED practices, an analysis is conducted to see how these savings are reflected and considered in their certification process. The scores act as an incentive for operators to achieve credits to gain higher certification levels. It is crucial to examine the full scoring perspective since LEED certification is based on a total of 110 points.

The scores are displayed in Table 5.10. Exploring the scores in the table, for example, it shows that similar scoring is assigned to Renewable Energy Credit and Access to Quality Transit. Despite this, there is a significant difference in the actual savings achieved by these credits. This highlights the importance of a deeper comparison to understand how LEED reflects environmental credit savings.

LEED Environmental Credits	**Score**	**Percentage Allocated Score / Total score**
Access to Quality Transit	5	5%
Bicycle Facilities	1	1%
Electric Vehicles	1	1%
Heat Island Reduction	2	2%
Enhanced Commissioning	6	5%
Optimise Energy Performance	18	16%
Advanced Energy Metering	1	1%
Renewable Energy	5	5%

Building Life-Cycle Impact Reduction	5	5%
Construction and Demolition Waste Management	2	2%

Table 5.10 Allocated Score for LEED Assessed Credits

Figure 5.6 graphically compares the actual average savings from each LEED credit to their respective score allocations within the LEED system. The figure reveals a significant misalignment between the LEED scoring system and the actual environmental impact. Specifically, for credits under the Energy and Atmosphere category, there is an underestimation of credits that have significant impact and savings, as shown in previous calculations. Additionally, there is an overestimation of credits with lower impact. It is important to explore how the certification total score look into these credits.

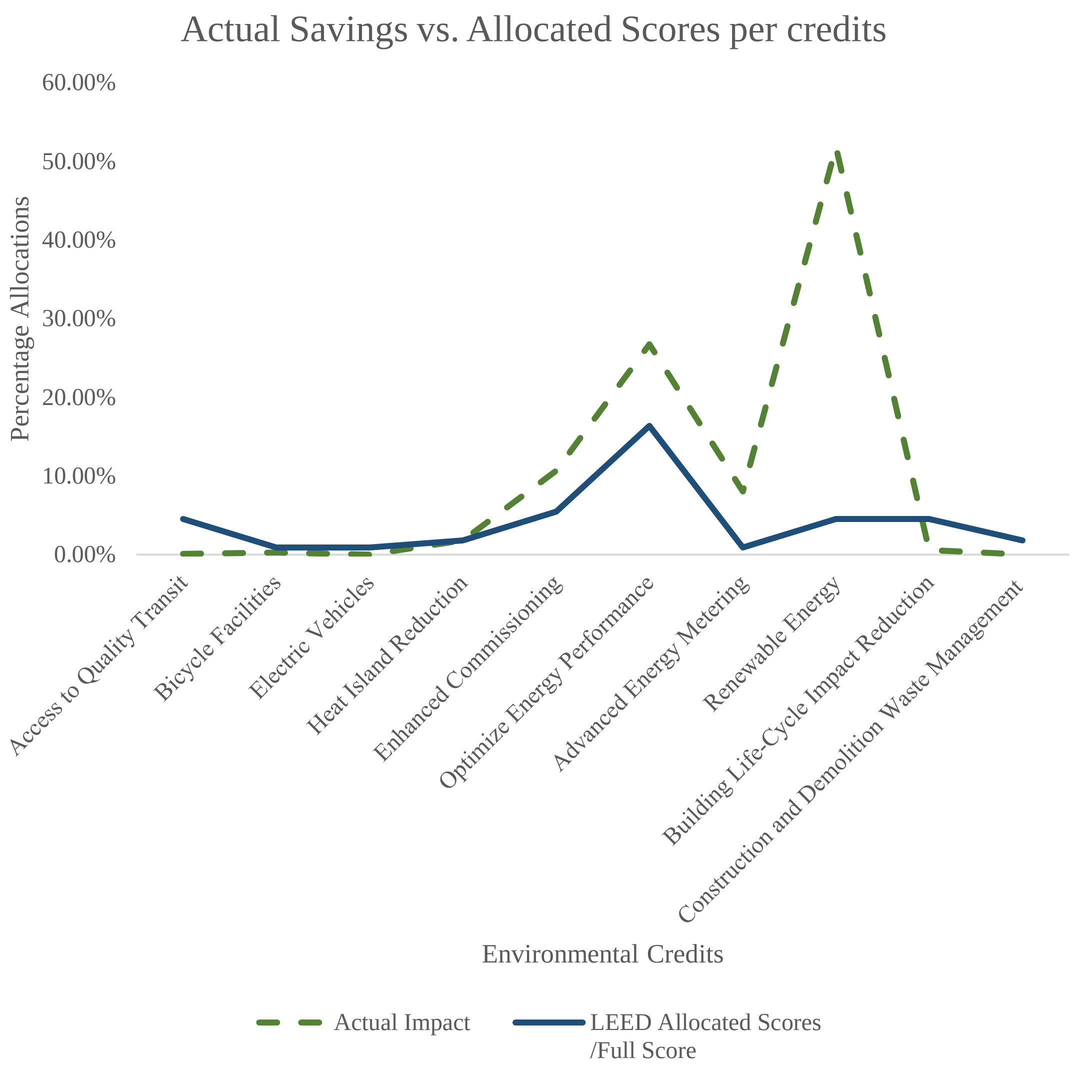

Figure 5.6 Comparison between LEED Score Allocation and Actual Environmental Impacts

For example, Enhanced Commissioning, Access to Quality Transit, Renewable Energy, and Building Life Cycle Impact Reduction credits each constitute 5% of the total LEED score, reflecting an equal effort to achieve these credits within the LEED system. However, these credits differ significantly in actual savings, providing 10%, 0.12%, 52%, and 0.58 % of savings respectively.

To quantify these observations, discrepancy and impact discrepancy values are calculated. These values show the inconsistencies between the LEED score allocations and the actual environmental savings, providing a comprehensive view of the overall scoring proportions.

Discrepancy metric measures the deviation of the LEED score proportion from the actual savings achieved relative to those actual savings. It quantifies how much the LEED score's assumption about a credit's environmental impact overestimates or underestimates the real impact achieved. This variance is expressed as a percentage of the Actual Savings, calculated using the following formula:

$$D = \frac{X_{LEED} - X_{Act}}{X_{Act}} \qquad \text{Eq 5.13}$$

Where,

D designates the discrepancy value and

X_{LEED}, LEED allocated Score contribution (%)

X_{Act}, Actual Savings contribution (%)

A positive discrepancy indicates that the LEED score proportion is higher than the actual savings, suggesting that LEED overestimates the credit’s impact (overvaluation). A negative discrepancy suggests that the LEED score proportion is lower than the actual savings, implying that LEED underestimates the effect of credit (undervaluation).

The Impact Discrepancy metric quantifies the significance of the discrepancy in absolute terms, considering the scale of actual environmental contributions. It measures the significance of the discrepancy by considering the actual environmental savings achieved. It reflects how much the discrepancy affects the perceived environmental benefit within the LEED scoring system. It is computed by multiplying the discrepancy by the Actual contribution.

$$I = D \times X_{Act}, \qquad \text{Eq 5.14}$$

Where, I designates the Impact Discrepancy calculated value.

The results of the calculated discrepancy and impact discrepancy are presented in Table 5.11.

LEED Environmental Credits	**Discrepancy**	**Impact Discrepancy**
Access to Quality Transit	3,806%	4%
Bicycle Facilities	267%	1%
Electric Vehicles	26,124%	1%
Heat Island Reduction	1%	0%
Enhanced Commissioning	-49%	-5%
Optimise Energy Performance	-39%	-10%
Advanced Energy Metering	-89%	-7%
Renewable Energy	-91%	-47%
Building Life-Cycle Impact Reduction	689%	4%
Construction and Demolition Waste Management	7,266%	2%

Table 5.11 Evaluation of LEED Credits: Discrepancies and Impact Discrepancy Values

Exploring discrepancies and impact discrepancies values is crucial for understanding actual savings and prioritising impactful credits. Starting with examples of credits that have the same LEED score contribution, we can see how these scores reflect perceived effort, savings, or importance. However, examining the discrepancies reveals a different story. For example, Access to quality transit credit has a Discrepancy Value of 3,806%, indicating significant overestimation. In contrast, Renewable Energy Credit, which has the highest actual savings, is underestimated by -91%. Translating these discrepancies to the actual impact on LEED scoring scheme: The former, with a 5-point contribution in the LEED score, needs its perceived impact to be reduced by 4% to accurately reflect its real savings. Meanwhile, the latter, with the same 5-point contribution, needs its perceived impact to be increased by 47% to accurately reflect its actual savings. Understanding these discrepancies highlights the misalignments between LEED scores and actual environmental savings. This insight is vital to help prioritise efforts towards credits that provide actual environmental benefits.

The discrepancies between the allocated LEED scores and the actual savings contributions of credits can be traced back to the origins of the LEED framework. LEED was initially developed with a primary focus on traditional construction and building types. Although a significant portion of points is allocated to the Energy and Atmosphere category, considerable emphasis is placed on other credits. These credits are deemed more important within the LEED framework for other building types compared to data centres. Data centres, with their unique energy profiles and operational requirements, were only introduced in later versions of LEED. This historical focus, along with overlapping priorities of credits allocated between data centres and other building types, may contribute to the observed discrepancies, as the rating system was not originally tailored to the specific needs and characteristics of data centres.

An article published by Arc, a software platform that collects, manages, and analyses data and communicates it as a score, shares that higher certification levels reveal higher emissions savings of CO_2. For example, it shows that the difference in carbon savings between each higher certification level and the Certified level is significant. It displays that the difference in savings between Certified and Gold is 33%, and between Certified and Platinum is 56% (ARC, 2019).

Looking at the results, this difference highly depends on the choice of credits selected. For instance, if a project contributes to 5 points from Access to Quality Transit Credit and ignores the 5 points from Renewable Energy, it will end up with just 0.12% actual savings compared to LEED scores. However, if the project contributes 5 points from the latter, it will achieve 52% of actual savings, assuming the maximum savings potential of this credit. Despite both credits contributing 5 points to the LEED score, Renewable Energy's significant actual savings demonstrate that the choice of credits greatly impacts overall environmental performance. This 5% LEED score contribution from this practice translates to substantial real-world savings but does not necessarily elevate the project from a certified to a platinum level, illustrating the misalignment between LEED scores and higher certification and true environmental benefits.

The calculated values presented in Table 5.11 help stakeholders, policy makers, and data centre operators by highlighting which LEED credits are most impactful. These calculations identify gaps where the current scoring system may not accurately reflect the actual sustainability performance of data centres. By pinpointing credits that are either highly effective or difficult to attain, stakeholders can focus their efforts on improving practices around the most significant sustainability factors. This also helps policy makers to focus on the most impactful credits not just the certification level.

Taking into consideration that LEED reflects on other aspects of sustainability, the next section will focus solely on the environmental credit proportions and how LEED reflects on them alone.

5.5.2 Focused Comparison Reflecting on LEED Points for Environmental Credit

This section examines the LEED scoring proportions dedicated solely to the 46 points allocated for environmental credits that contribute to emissions reduction. By isolating these points, we can achieve a more precise evaluation of how accurately LEED scores reflect actual environmental performance, which is crucial for understanding the true emission savings impact of the certification system.

If an operator solely focused on attaining these credits, the 46 points are associated with the environmental credits necessary to only attain a Certified level of LEED certification. By focusing exclusively on these points, this section aims to determine how well LEED scores align with the actual savings achieved through environmental initiatives.

Figure 5.7 graphically compares actual average savings from each LEED credit to their respective score allocations from the 46-scoring allocation within the LEED system. This comparison reveals significant discrepancies when these environmental credits are viewed in isolation versus within the total LEED certification score shown in the previous subsection.

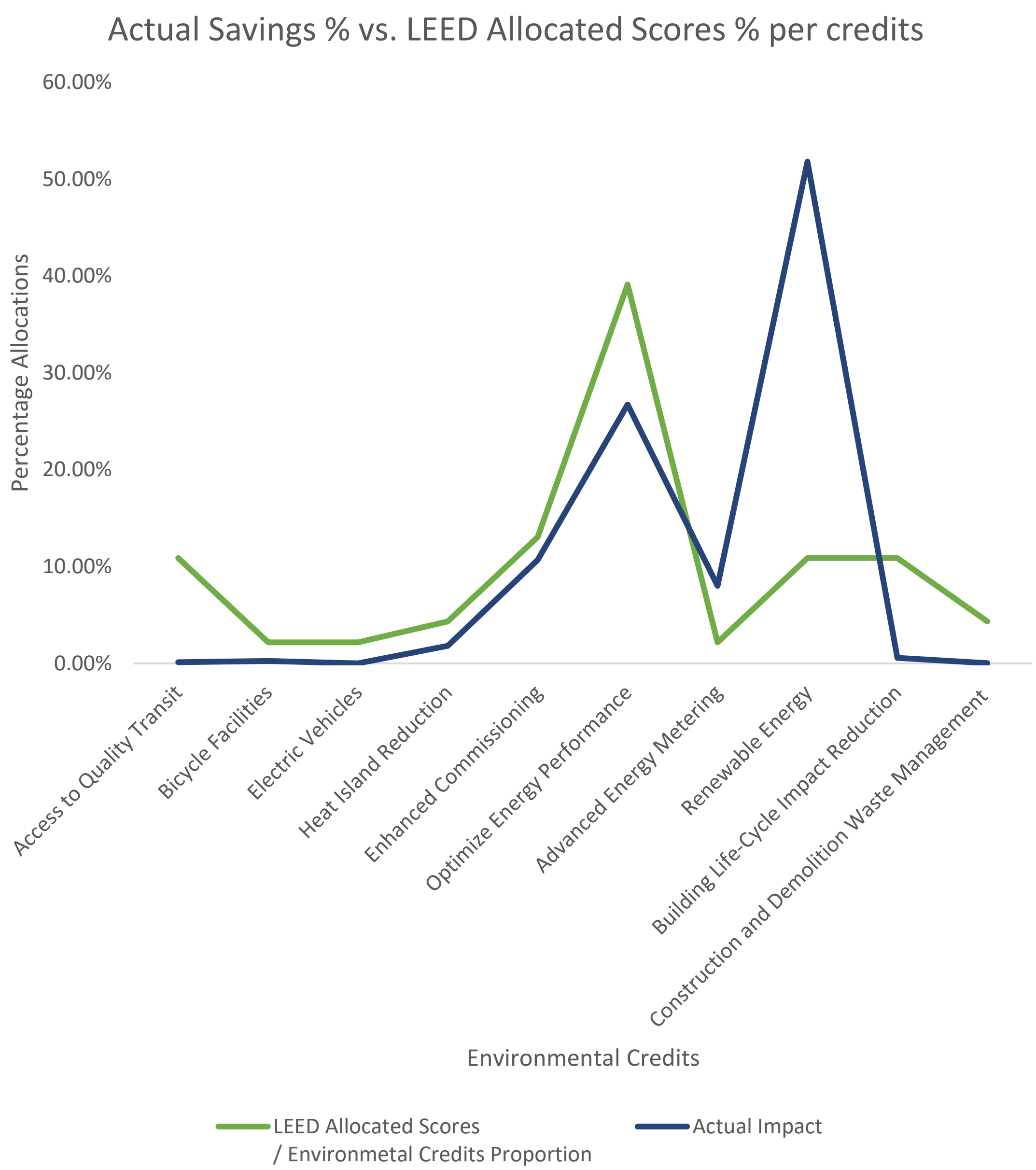

Figure 5.7 Discrepancies Between Actual Savings and LEED Allocated Scores by Credit

The figure still reveals a significant misalignment between the assigned LEED scores and their actual environmental contributions within these facilities. For example, despite making up over 10% of the overall LEED score, the Access to Quality Transit credit contributes less than 1% to the actual environmental improvements in data centres. Conversely, the Renewable Energy credit, allocated under 5% of the total LEED score, exemplifies a potential underestimation of the credit's environmental benefit by the LEED system.

On the other hand, some credits appear overestimated when considered as part of the total certification score but are underestimated when focusing solely on the 46 environmental points. However, these credits have a significant impact on data centre savings. This demonstrates that the 46 points and the current scheme is not enough and does not fully account for the substantial differences in environmental impact among credits. This misalignment highlights the necessity of refining LEED's scheme to better capture the true sustainability contributions of each credit.

This result is further examined in the next section, which compares two LEED-certified data centres.

5.6 Evaluating LEED Certification Effectiveness: A Comparative Analysis of Gold and Certified Levels

In this section, a comparison between two data centres that are LEED certified as Gold (2nd best level) and Certified (4th / lowest level) respectively is conducted. The analysis uses the score distribution of the two certifications, shown in in Table 5.12, and apply that to the five case studies to assess whether the score distribution would reflect the environmental performance.

In the analysis, it is assumed that there is a direct correlation between the scores achieved and the potential environmental impact opportunity realised from the corresponding credit. For instance, a score of 5 out of 10 suggests a 50% reduction in impact attributed to that particular credit. Similarly, a 100% full score assumes a full utilisation of the potential impact.

LEED Environmental Credits	**Gold Profile**		**Certified Profile**	
	Score	% of Total Score	Score	% of Total Score
Access to Quality Transit	5	100%	0	0%
Bicycle Facilities	0	0%	1	100%
Electric Vehicles	1	100%	0	0%
Heat Island Reduction	2	100%	0	0%
Enhanced Commissioning	5	83%	3	50%

Optimise Energy Performance	6	33%	18	100%
Advanced Energy Metering	1	100%	1	100%
Renewable Energy	0	0%	0	0%
Building Lifecycle Impact Reduction	5	100%	0	0%
Construction and Demolition Waste Management	1	50%	1	50%

Table 5.12 Score Proportion of 2 Different LEED Certified Profiles.

To further our analysis, we apply these scores to the proportion of actual environmental savings from each credit. To estimate the % impact reduction of CO_2 emissions for each case study, given a particular certifications profile, we assume that the environmental impact savings are in line with the certification score achieved for the credit. For example, in case study 1 the Access to Quality transit credit represents 0.13% of the potential environmental impact for the case study. When calculating the impact reduction under the Gold profile, which has a score of 100%, the full 0.13% opportunity is accounted. Similarly, when calculating the impact reduction under the Certified profile, where the credit received a score of 0, no reduction is accounted. Based on this methodology, the percentage impact reduction of CO_2 emissions for each of the 5 case studies is calculated based on the 2 certification profiles. The results are shown in Figure 5.8.

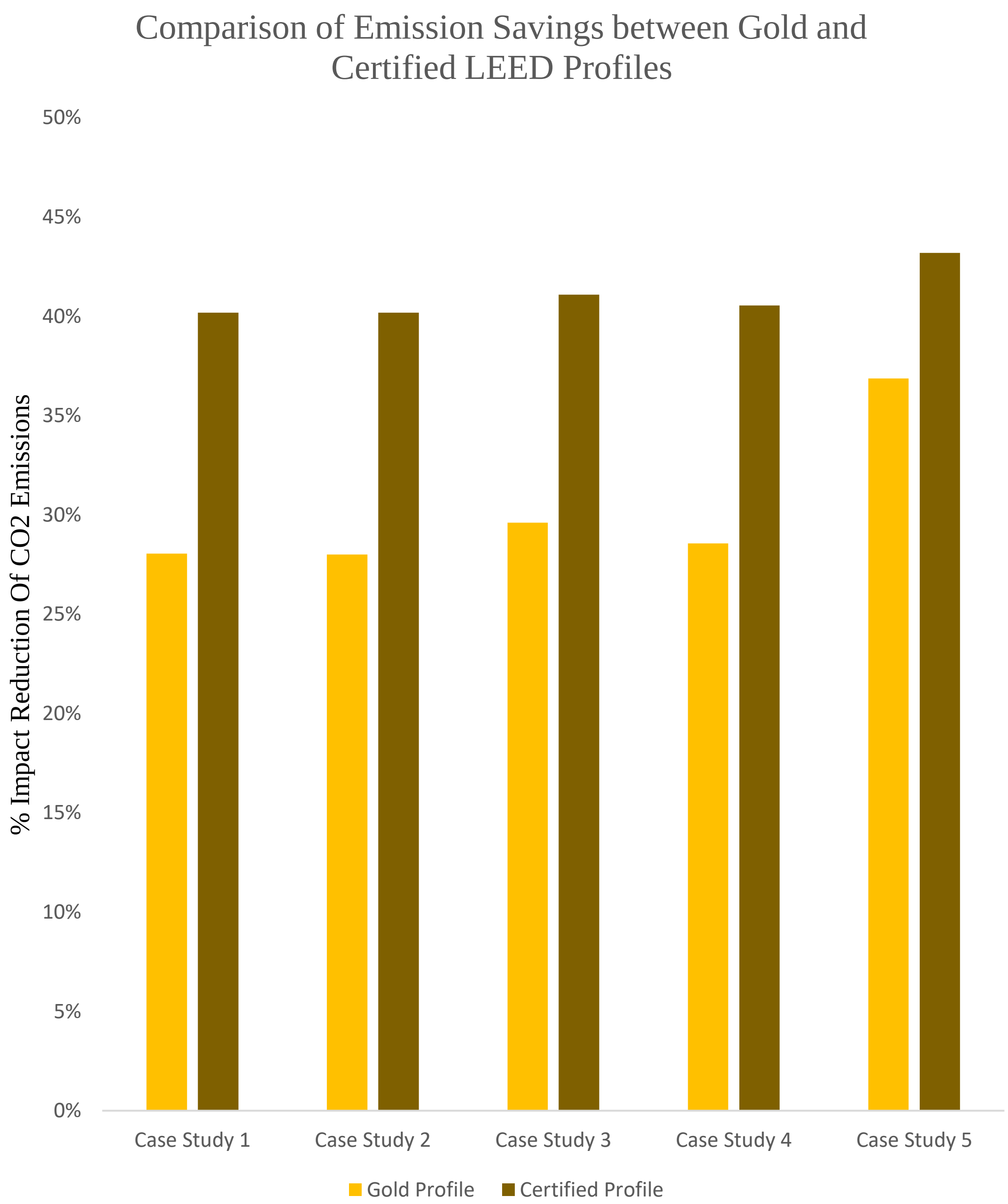

Figure 5.8 The Emission Savings Achieved by Gold and Certified LEED Profiles Applied to the 5 Case Studies

The results clearly show that the Certified profile yields higher CO_2 savings compared to the Gold profile, across all the 5 case studies. This challenges the reliability of the correlation between LEED certification levels and environmental performance. The outcome supports our preliminary analysis around the LEED scoring system's effectiveness in assessing data centres' true environmental performance.

The current scoring system allows for the accumulation of points through credits that have less potential impact on CO_2 savings. This can occur because the certification process does not always prioritise credits based on their environmental impact. For instance, buildings may earn high scores from easier-to-implement measures that have low impact, such as credits related to site selection or modest energy efficiency improvements, rather than from substantial impact saving measures. Consequently, Certified buildings, may achieve greater environmental savings than those with higher certification level.

Next subsection presents discusses further the results.

5.7 Discussion

The LEED certification system rewards positive sustainability practices but does not penalise buildings for negative or neutral performances. This approach could potentially allow buildings that incorporate non-sustainable elements to still achieve certification (Denzer & Hedges, 2011). Furthermore, LEED applies a uniform scoring criterion across various building types, including data centres, which may not adequately reflect their unique environmental impacts and operational demands. Our analysis has revealed a significant misalignment between the expected environmental outcomes as predicted by LEED scores and the actual savings achieved. This section further discusses the differences in achievements of credits and actual savings.

In Chapter 4, it was shown that among the least achieved credits is green power and renewable energy, which is reflected as the renewable energy credit in LEED v4.1 and this chapter. On the other hand, the current chapter demonstrates that the most significant savings are achieved within this credit. This discrepancy indicates that the certification system is not providing sufficient incentives for operators to pursue this credit and its associated environmental benefits. The lack of rewarding incentives for renewable energy credits might be discouraging operators from aiming for higher achievements in this area, thereby missing out on substantial environmental savings.

Moreover, with the same scoring credits, data centres may achieve Access to Quality Transit, which has an average score achievement of 47%—almost 50% higher than renewable energy. While both credits contribute similar scores to the LEED certification, the actual savings from Access to Quality Transit are significantly lower compared to those from renewable energy. This highlights the need for data centres to have more incentives and better-scored credits that genuinely reflect higher savings.

The under-achievement of certain credits is critical, as even when maximum savings are realised, they are not always reflected proportionately in the LEED scores. For instance, a case study where a facility achieved only one point in the Optimise Energy Performance credit resulted in a silver certification, while a higher score in the same credit was associated with a certified level. This inconsistency demonstrates that achieving higher certification levels does not necessarily correlate with greater environmental savings, particularly in data centres.

These findings highlight the need for a more nuanced approach to LEED scoring, especially for building types like data centres that have distinct operational demands and environmental impacts. The uniformity in scoring across diverse building types may lead to a misrepresentation of true sustainability performance. Specifically, the misalignment between LEED scores and actual environmental savings suggests that the certification system might be overvaluing some credits while undervaluing others, thus not accurately reflecting the environmental impact of the buildings.

Moreover, the discussion in Chapter 4 and this chapter collectively underscores the importance of revising LEED criteria to better incentivise and accurately assess high-impact sustainability practices. For example, making renewable energy credits more rewarding could drive operators to invest more in green power solutions, leading to higher actual savings. Similarly, refining the metrics for credits like Optimise Energy Performance to reflect incremental improvements more accurately could encourage operators to strive for higher efficiency levels.

In summary, the current LEED certification system, while promoting sustainability, falls short in incentivising the most impactful practices due to its uniform scoring approach and lack of penalties for neutral or negative performances. There is a clear need for LEED to evolve and incorporate a more granular and precise assessment methodology that recognises the unique characteristics and challenges of different building types, particularly data centres. By doing so, LEED can ensure that its scores more accurately reflect actual environmental savings, thereby driving more meaningful and substantial sustainability improvements in the built environment.

The next section will summarise the findings of this chapter and outline the path for future research steps.

5.8 Conclusion

This chapter reveals the savings from LEED environmental credits. Analysis is presented in different ways. The dual analysis of CO_2 emissions, both non-normalised and normalised by IT load, offers distinct yet complementary perspectives on energy efficiency in data centres. The non-normalised view highlights the absolute emission reductions, particularly beneficial for understanding the total environmental impact of larger operations like hyperscalers. Conversely, the normalised data provide critical insights into efficiency per unit of IT load, revealing how data centres with higher grid intensity can achieve significant proportional savings. Together, these perspectives underscore the complexity of energy management in data centres and validate the necessity of employing both approaches to obtain a holistic understanding. By embracing both viewpoints, policymakers and data centre managers can tailor their strategies more effectively, choosing the right approach based on specific operational contexts and regional energy characteristics.

The findings suggest that while LEED certifications aim to incentivise sustainable building practices, discrepancies exist between how scores are awarded and the actual environmental outcomes. These discrepancies necessitate a critical review and recalibration of the scoring process. This recalibration should take into account the unique demands and impacts of data centres to ensure that LEED certification remains a reliable indicator of genuine sustainable practices.

The forthcoming chapter addresses gaps in the LEED certification process, proposing a new scoring scheme and refining considerations to better align with the diverse needs of modern data centre projects.

Chapter 6. Addressing the Gaps in LEED Environmental Credits

6.1 Introduction

LEED's existing guidelines evaluate all building types, including data centres, with a standard framework that fails to recognise these specialised facilities' distinct attributes and operational specifics. While there are a few credits that partially address data centres within some options, these do not comprehensively reflect the specific requirements and operational dynamics of data centres. Chapter 5 have quantitatively shown a misalignment between the actual environmental savings achieved and how these are reflected in LEED certifications. Despite achieving high levels of certification, there remains a disconnect between the awarded LEED scores and the actual impact and savings of the facilities. This research aims to investigate the effectiveness of LEED in the data centre industry and explores how the framework can be adapted to be more reflective and effective.

Data centres vary significantly in type, size, and the influence of regional factors on sustainability. This chapter addresses the gaps in the LEED framework against data centres by proposing new scoring criteria specifically tailored to the environmental aspects of sustainability. Moreover, the chapter addresses gaps in the current descriptions of LEED credits to more accurately differentiate data centres and integrate LEED criteria with current data centre best practices and standards.

The chapter proceeds with Section 6.2, which introduces a newly proposed scoring scheme specifically designed to better reflect the actual environmental performance observed in data centres. Section 6.3 then examines qualitative gaps in current LEED credits, focusing on enhancing descriptions, requirements, and criteria to represent the unique needs of data centres more accurately. This section analyses how current criteria can be adjusted to better capture the distinct operational and environmental challenges these facilities face. Wrapping up the chapter, Section 6.4 applies a SWOT (Strengths, Weaknesses, Opportunities, Threats) analysis to LEED's application in data centres, providing a comprehensive evaluation of the existing certification criteria, ensuring thorough consideration of potential impacts and improvements.

6.2 Proposal for New LEED Criteria Scoring Scheme for Data Centres

LEED currently assesses building sustainability through a system of impact categories and components. The association between LEED credit requirements and the goals of each impact category is measured and scaled based on effectiveness, duration of effect, and control, which denotes the individual or entity primarily responsible for achieving the expected outcomes of the credit. LEED does not uniformly scale the different impact categories. For instance, the weighting criteria allocate 35% to global warming impact and 20% to human health. However, the weighting prioritisation doesn't align perfectly with all building types, especially data centres.

The scaling system used in data centres is similar to that applied to other building types, despite their distinct impacts and types of occupants. This uniform approach fails to address data centres' unique environmental and operational characteristics, potentially leading to misaligned incentives and outcomes. The current LEED scheme lacks the granularity needed to allocate weights due to substantial differences in impact. Given the diverse nature of data centres, a more tailored approach is essential. A single criterion is not suitable for data centre facilities of different sizes and locations. Various factors, such as grid intensity and the presence of renewable energy, impact actual savings and environmental impact. Therefore, it is crucial to implement multiple scoring schemes to better reflect these diverse parameters.

One approach is to categorise data centres based on their characteristics and location. For instance, *Medium-Sized Data Centres in Higher Grid Intensity Areas*, which is similar to our case studies (1-4). However, in Case 5, significant differences in data centre size and location, particularly the grid intensity and presence of renewable energy, highlighted the need for varied scoring schemes. The presence of renewable energy reduced the impact of scope 2 emissions, shifting the focus to the importance of savings from scope 3 emissions during the construction phase. Additionally, the larger size of the data centre increased the construction impact, amplifying the potential savings. Thus, another category could be *Hyperscale Data Centres with Low Grid Intensity*.

The proposed scoring schemes are designed to offer a more tailored approach to environmental sustainability, ensuring that LEED certification for data centres genuinely reflects significant environmental stewardship and operational efficiency. The scoring system is designed so that the minimum score for credit allocation must be equal to 1, and all scores are expressed as whole numbers, aligning with the LEED scoring methodology. To determine the appropriate scoring, we used a trial-and-error approach to ensure that the overall score reflects a contribution across various credits. Scores are then allocated based on the actual percentage of contribution calculated in Chapter 5. The total score of 29,000 for environmental impact was specifically set to ensure a credit allocation of at least 1 for the minimum impact while considering the varied significance of each credit.

Table 6.1 presents the first proposed new scoring scheme that suits the medium sized, higher grid data centres.

The score is calculated as the :

Average potential opportunity savings × Total Score,

For example, for the Electric Vehicle Credit:

0.0035% (as per Table 5.9) × 29000 = 1

LEED Environmental Credits	Proposed Score
Access to Quality Transit	34
Bicycle Facilities	72
Electric Vehicles	1
Heat Island Reduction	523
Enhanced Commissioning	3,100
Optimise Energy Performance	7,749
Advanced Energy Metering	2,325
Renewable Energy	15,023
Building Life-Cycle Impact Reduction	167
Construction and Demolition Waste Management	7
Total	29,000

Table 6.1 Proposal of New Score Allocation

The new score allocated for environmental impact is 29,000. The lowest score of 1 corresponds to the Electric Vehicle credit, reflecting the least amount of savings. Conversely, the highest score, 15,023 points, is allocated to the Renewable Energy credit. The proposed scoring system better reflects the unique nature of data centres and addresses discrepancies between practices. Various factors impact actual savings, necessitating flexible scoring schemes to accurately reflect the diverse parameters of data centres and their locations. These findings underscore the need for flexibility in implementing more than one scoring scheme, allowing for adaptation to different contexts and better reflecting the unique characteristics of each data centre. The second proposed scoring scheme is introduced in Table 6.2, indicating the shift of scores from renewable energy to other credits to adapt to impact and savings reflectance.

LEED Environmental Credits	Proposed Scores
Access to Quality Transit	20
Bicycle Facilities	30
Electric Vehicles	1
Heat Island Reduction	177
Enhanced Commissioning	3,318
Optimise Energy Performance	8,296
Advanced Energy Metering	2,489
Renewable Energy	12,140
Building Life-Cycle Impact Reduction	2,425
Construction and Demolition Waste Management	104
Total	29,000

Table 6.2 Proposal of New Score Allocation #2

The tables show that the renewable energy credit score is decreased to better accommodate and incentivise other credits that have increased savings, such as the Building Life Cycle Impact Reduction Credit. The scores are verified by comparing them to the actual impact and applying them to previously assessed certified cases in Chapter 7.

Another potential approach is to develop a weighted scoring criterion. This could involve assigning different weights to credits based on their impact and relevance to specific data centre types and locations. This method would further refine the scoring system to ensure that it accurately reflects the environmental performance of diverse data centres.

The next section provides recommendations on how LEED credits can be refined to better distinguish the specific characteristics and operational demands of data centres.

6.3 Refining LEED Credit Descriptions for Data Centres

In this section, a thorough review is undertaken of environmental credits within the LEED certification framework as they are applied to data centres. The aim is to identify gaps and shortcomings in how these credits are described, implemented, and reflected. The analysis is geared towards proposing targeted enhancements to better align these credits with the unique environmental and operational realities of data centres. To ensure that these enhancements are robust and specifically tailored, data centre-specific standards such as EN 50600-5-1 and EU Code of Conduct are referenced.

Central to our evaluative methodology is the use of an impact scale developed specifically for this analysis. This scale categorises the environmental impact of each LEED credit into four distinct levels low, medium, high, and very high based on the actual impact savings calculated in Chapter 5.

- Low Impact (0-5%): Credits that offer minimal environmental improvements within data centres.
- Medium Impact (5-25%): Credits that provide moderate environmental benefits within data centres.
- High Impact (25-50%): Credits that are essential for substantial sustainability improvements within data centres.
- Very High Impact (50%+): Credits that have transformative impacts, driving major environmental advancements.

These categories were derived from empirical data, reflecting the true efficacy of each credit in operational terms. This categorisation allows us to critically assess each credit's relative efficacy. Moreover, we highlight where LEED standards may overestimate or underestimate the environmental contributions of specific credits according to discrepancy and impact metrics calculated in Chapter 5. The intent of assessing the overestimation or underestimation of LEED credits is to identify discrepancies within the LEED scale that may lead to misleading applicability and granularity for data centres.

This analysis methodically addresses each credit by first detailing its requirements, then identifying existing gaps, assessing its impact level and relative reflectance of LEED scores, and finally proposing specific adjustments to ensure the credits are realistically aligned with the operational characteristics of data centres. This thorough categorization not only advances our understanding of the practical implications of each credit but also strategically guides stakeholders in prioritizing their sustainability efforts more effectively.

6.3.1 Location and Transportation Environmental Credits Gaps Analysis

Within the LEED certification framework, the Location and Transportation category includes several credits aimed at reducing the environmental impact associated with commuting. For data centres, which primarily house computers and networking servers with relatively low human occupancy, the application of these credits presents unique challenges.

Each credit within this category is examined to determine its intent and the specific gaps that exist. Given that the impact level, score alignment, and proposed adjustments for addressing gaps are similar across all credits within this category, these elements are discussed collectively rather than individually for each credit. Therefore, under each credit, its intent and the identified gaps are presented. Following this, a combined discussion is provided, detailing the overall impact level, scores alignment, and proposed adjustments to address the gaps across all credits.

Access to Quality Transit

Intent

This credit is awarded to projects located close to bus stops and transit stations, with the aim of reducing reliance on private vehicles.

Gap

Data centres have significantly lower occupancy and thus reduced commuting needs, making this credit less relevant. The standard requirements do not account for the operational characteristics of data centres, which typically see fewer daily commutes.

Bicycle Facilities

Intent

Includes provisions for bicycle storage and shower facilities to encourage cycling.

Gap

Mainly, the requirement is misaligned with the nature of data centres, which typically have few to negligible numbers of onsite staff, leading to underutilisation of these facilities. Moreover, in some regions, the absence of established bicycle infrastructure renders this requirement impractical and largely irrelevant. These areas lack safe or feasible cycling routes, and consequently, facilities could be unfairly penalised for not meeting LEED criteria that are unattainable due to external circumstances beyond their control.

Electric Vehicle Credit

Intent

Encourages the installation of EV charging infrastructure to support the use of electric vehicles.

Gap

Similar to the other credits, the utility of EV charging stations is limited in data centres due to the smaller number of human occupants and their commuting patterns.

Impact Level

All these credits have a *Low Impact* in the context of data centres, as they all contribute less than 1% to overall savings. This highlights a fundamental misalignment with the operational realities of data centres, where commuting needs are minimal.

Score Alignment

These credits are consistently *overestimated* in LEED assessments for data centres. The contribution of these credits to reducing environmental impacts in the short term is often overstated, given the limited number of daily commutes typically associated with data centres.

Proposed Adjustments

Introduce flexibility such as exemptions or significant adjustments for data centres, reflecting the low number of commuting staff and the minimal environmental impact of enhanced transit access. This adjustment could allow data centres to opt-out or meet significantly reduced criteria, taking into account the actual usage of such facilities.

By implementing these adjustments, LEED can better accommodate the specific needs of data centres, ensuring that the credits are both meaningful and appropriately scaled to reflect the true environmental contributions of these facilities. This more tailored approach would promote genuine sustainability efforts rather than applying a one-size-fits-all model that does not align with the operational characteristics of all building types.

6.3.2 Sustainable Sites environmental credits Gap Analysis

Within the LEED certification framework, the Sustainable Sites category addresses the environmental impacts associated with the location and management of a building. This analysis focuses specifically on the Heat Island Reduction credit, which is particularly relevant to the cooling efficiency of data centres.

Heat Island Reduction

Intent

LEED Heat Island Reduction credit focuses on minimising the heat island effect by implementing strategies that reduce heat absorption and enhance the thermal performance of building envelopes and surrounding surfaces. By using reflective materials on roofs and pavements, buildings can absorb less heat during hot weather conditions, which can subsequently reduce the demand for air conditioning and lower overall energy consumption.

Gaps

The effectiveness of heat island reduction strategies, such as cool roofs, is significantly influenced by variables including ambient temperature, daily temperature fluctuations, solar radiation intensity, and the reflective and emissive properties of the materials used. In the context of data centres, which necessitate intensive cooling, the typical reductions in heat absorption achieved by these measures do not directly translate into proportional energy savings. For instance, while cool roofs might yield energy savings of up to 24% in hot climate residential buildings (Algarni, 2018), in data centres the savings may only be around 8% due to their higher per square metre cooling requirements. Detailed calculations is found in Chapter 5.

Furthermore, the current LEED recommendations for minimum Solar Reflectance (SR) values fail to account for regional variations that critically influence their effectiveness. In regions like the Kingdom of Saudi Arabia, for example, typical SR values can reach as high as 0.6, substantially surpassing LEED's minimum requirements.

There are various values for cool and green roofs savings that vary significantly between countries. For instance, savings can be as high as 24% in arid climates as Saudi Arabia. Moreover, within the same country, values can differ significantly between cities, sometimes by more than 5% (Algarni, 2018). In cold climate countries such as London, cool roofs can result in savings as low as 2% (Virk, et al., 2015). In China, which has a diverse climate ranging from temperate to tropical, savings can range between 8% and 12.6% (Zhao & Zhang, 2023). It is important to note that these figures are based on studies conducted on residential and office buildings. Data centres, however, tend to yield lower savings due to the different cooling needs per square meter, which can result in negligible savings in cold climates.

This credit highlights a crucial absence of comprehensive data centre-specific research. This gap hinders accurate evaluations of the impact that heat island reduction strategies have on energy consumption and environmental performance in data centres. The effectiveness of these measures varies significantly across different climates. This variability complicates the application of a one-size-fits-all standard. Additionally, different types and sizes of data centres have varying cooling requirements, leading to different savings values for these practices.

Impact Level

The credit indicated having *a Low Impact,* empirical results indicate that actual savings from implementing heat island reduction strategies in data centres are around 1.92%.

Although there is some reduction in energy use, it is less impactful compared to other strategies that could be employed within data centres.

Score Alignment

This credit is *Slightly Overestimated* in LEED's criteria for data centres. Savings tend to be lower than estimated in this credit for data centres due to its high energy usage and operational impact.

Proposed Adjustments

There is a need for more localised or tailored approaches to effectively address these variations. Moreover, it is essential to consider the different needs for different types and sizes of data centres to ensure accurate evaluation and implementation of energy-saving practices.

6.3.3 Energy and Atmosphere Environmental Credits Gaps Analysis

The Energy and Atmosphere category focuses on energy savings, which directly translate to emissions reductions. This category yields the highest savings based on our calculations, proving to have a high impact on the energy consumption during the operations phase. Data centres are among the most energy-intensive building types, consuming 10 to 50 times the energy per floor space of a typical commercial office building, underscoring the critical importance of this category (EERE, 2013).

While the LEED credits within this category aim to optimise energy performance and promote the use of renewable energy, several gaps remain in their applicability and effectiveness for data centres. These gaps arise from the unique characteristics and high energy demands of data centres, which differ significantly from other building types. Inefficient data centres can consume significant amounts of power, straining the available renewable energy resources. This issue is evident in Ireland, where data centres are projected to consume 23% of all electricity demand by 2030 (SEAi, 2022), emphasising the importance of both energy efficiency and renewable energy usage to ensure sustainability.

This subsection examines credits within Energy and Atmosphere category identifying gaps and proposed solutions to improve relevance and effectiveness for data centres.

Enhanced Commissioning

Intent

This credit aims to ensure that the design, construction, and eventual operation of a project adhere to the owner's specific requirements for energy, water, indoor environmental quality, and durability. The primary objective is to optimise system performance and prevent inefficiencies that may result from omitting crucial commissioning steps. Effective commissioning involves a comprehensive approach to testing, verifying, and documenting the functionality of critical infrastructure, including power distribution, cooling systems, and security measures.

Gaps

In terms of the practice itself, there are no noticeable gaps that need to be addressed. The commissioning process is well-established and effective in ensuring that facilities' systems and components are installed and function according to design specifications. This comprehensive approach to testing, verification, and documentation supports optimal system performance and operational efficiency.

Impact Level

This credit is considered to have a *medium impact* for data centres. When implemented effectively, the practice results in considerable savings and enhances efficiency. Proper commissioning can lead to significant operational savings and improved performance in data centres.

Score Alignment

This credit is considered *underestimated* based on the LEED scale. While the discrepancy value is relatively low compared to those found in the Transportation section, the overestimation highlights a lack of granularity in the LEED scoring system when compared to other savings practices.

Proposed Adjustments

No adjustments are needed for the practice itself. The necessary adjustments lie in the scoring and reflectance of the practice within the LEED framework.

Advanced Energy Metering

Intent

To achieve this credit, advanced energy metering must be installed for all whole-building energy sources used by the building, as well as for any individual energy end uses that represent 10% or more of the building's total annual consumption. The advanced energy metering system must have several key characteristics: meters must be permanently installed and record data at intervals of one hour or less, transmitting this data to a remote location. For electricity, meters must record both consumption and demand, and whole-building electricity meters should also record the power factor if appropriate. The data collection system must utilise a local area network, building automation system, wireless network, or comparable communication infrastructure, and it must be capable of storing all meter data for at least 36 months. Additionally, the data must be remotely accessible, and all meters within the system must be able to report hourly, daily, monthly, and annual energy use. This credit helps data centres' operators identify inefficiencies, track energy usage trends, and pinpoints areas for improvement.

Gaps

Metering in data centres is crucial and requires higher levels and more detailed specifications as outlined in standards and best practices for data centres. Consequently, gaps need to be identified starting from the prerequisite and minimum requirements for this practice. The prerequisite for LEED metering focuses on building-level data and monthly interval readings. When compared to the minimum level of maturity in the EN 50600-5-1 Maturity Model for data centres, it becomes clear that the LEED credit aligns more closely with basic requirements.

For instance, to achieve the minimum level of maturity according to data centre best practices, meters must measure the total energy consumption within the data centre boundary, with readings automated daily. A higher level of maturity involves improving visibility and granularity through distribution board-level metering, with readings taken every 15 minutes. Minimum requirements of metering are needed for each element of a data centre including the environmental control, ICT devices, and power supply. Moreover, these requirements extend beyond energy in environmental controls and ICT devices. At a minimum level, temperature must be measured at individual aisle levels, and air supply temperatures must be monitored to manage airflow and prevent over-cooling. For ICT compute devices, automated daily readings of energy usage, inlet air temperature, and CPU utilisation are required.

The broad scope of LEED metering fails to address the granularity needed for data centres, where detailed monitoring of individual systems and components is essential for effective energy management. LEED does not encompass the full range of necessary metering, including temperature and ICT device-specific metrics, which are critical for optimising data centre performance and energy efficiency.

Impact Level

This practice has a *Medium level of impact.* When properly implemented, it significantly enhances transparency by providing detailed insights into energy usage. This transparency allows for the identification of inefficiencies, enabling targeted interventions. As a result, considerable energy savings and increased operational efficiency can be achieved. Effective metering practices ensure that energy consumption patterns are closely monitored, leading to informed decisions and optimised performance.

Score Alignment

This practice is *underestimated* in the LEED scale and scoring reflectance. It is crucial for data centre efficiency and transparency, and it yields significant savings if incorporated well.

Proposed Adjustments

The credit requirements should be enhanced to include more granular and frequent metering aligned with data centre standards and best practices. This includes automated daily readings, distribution board-level metering, and comprehensive monitoring of environmental conditions and ICT equipment. Incorporating a more detailed and specific approach to metering, aligned with the standards set by EN 50600-5-1 and other relevant best practices for data centres, is essential. Adjustments should start with the prerequisites and minimum level requirements for data centres.

Optimise Energy Efficiency

Intent

The intent of this credit involves reducing energy use and greenhouse gas emissions associated with data centre operations. By enhancing energy performance, data centres can significantly decrease their environmental impact and operational costs, improve sustainability, and ensure that energy resources are used efficiently.

Gaps

While LEED provides a framework for enhancing energy performance and specifies percentages for potential energy savings, it currently lacks specific guidelines or requirements that mandate the adoption of industry-recognised best practices tailored to IT environments, power and cooling energy use. This oversight means that while a building may achieve a certain percentage of energy efficiency improvement, it may not fully capitalise on advanced energy-saving strategies uniquely applicable to data centres. Key practices such as server virtualisation, efficient data storage solutions, and advanced power management for IT equipment are critical for maximising energy savings in data centres but are not explicitly addressed in the LEED framework.

Moreover, it lacks the best practices of cooling and power usage in data centre that introduces and reflects better energy efficiency.

Impact Level

This credit has a *high impact* on efficiency and emissions savings.

Score Alignment

This practice is *underestimated* in the LEED scale and scoring reflectance. The credit is crucial for data centre efficiency and transparency, and it yields significant savings if incorporated well.

Proposed Adjustment

To improve the relevance and effectiveness of the Optimizing Energy Performance credit, it is essential to incorporate best practices from standards such as EN 50600, focusing on efficiency in ICT, environmental control, and power management. This includes specific measures like server virtualisation, advanced power management for IT equipment, and optimised cooling strategies. Developing specific guidelines for different types of data centre operators (colocation, enterprise, hyperscalers) is crucial, recognising that some practices are endorsed by colocation operators while the responsibility for others lies with the colocation clients.

Renewable Energy

Intent

This credit, now combined, was previously divided into two separate credits in LEED v4.0 focusing on off-site and on-site renewable energies, separately. It aims to decrease dependency on fossil fuels and shift towards greener sources of energy. The intent of this credit is to promote the use of renewable energy to reduce greenhouse gas emissions and support environmental sustainability. By integrating renewable energy sources, this credit plays a crucial role in reducing overall emissions and fostering a more sustainable energy landscape.

Gaps

When it comes to this credit, on-site renewable energies are awarded more points than off-site or Green-E certifications. However, achieving on-site renewable energy has limited potentials compared to off-site. It doesn't only involve significant effort and often higher costs but also, requires substantial land for installations. To illustrate, let's consider a theoretical scenario involving a colocation data centre in the United Kingdom:

- Assume a typical data centre example with an average rack density of 5 kW/m²
- Solar panels, on average, produce between 150 to 200 W/m^2. For this calculation, we use the upper bound value, 200 W/m^2 (Renogy UK, 2022).
- The average sunlight exposure in the UK is approximately 1435 hrs per yr (Statista, 2023).

The total energy generated per square meter of solar panels in a year, providing a basis for estimating the total energy production for a given area of solar panels:

$$Annual\ Energy\ Yield = 200 \times 1435 = 287{,}000\ Wh\ /m^2.yr$$

The average power output per square meter of solar panels over the course of a year:

$$Annual\ Power\ Rate = \frac{287{,}000\ Wh/m^2}{8760\ hrs/year} = 32.8\ W/m2$$

$$Demand\ to\ Supply\ Ratio = \frac{5}{0.0328} = 152$$

This result indicates that about 152 times the data centre area would be required in solar panels to meet its total power demands using solar energy alone. To meet just 20% of its power needs with onsite renewable energy, the area required reduces to about 30 times the data centre's footprint. This calculation highlights the space requirements and challenges associated with on-site renewable energy installations.

Despite these efforts, the intermittent nature of renewable energy, such as solar power, means that it cannot provide a consistent supply. Solar energy is not available at night and can be less effective during cloudy days, which means data centres will still need to rely on the offsite grid during these times. Moreover, different goals and types of data centres may have varying peak hours and capacity needs, further complicating reliance solely on on-site renewables.

Impact Level

This credit has a *very high impact* due to its potential to significantly reduce reliance on fossil fuels. By incorporating renewable energy sources, data centres can effectively displace the emissions associated with traditional fuel use. The transition to renewable energy not only reduces greenhouse gas emissions but also supports the broader goal of sustainability by promoting cleaner energy alternatives. Consequently, this credit is highly effective in achieving substantial environmental benefits through fuel displacement and reduced carbon footprint.

Score Alignment

Renewable Energy credit is *underestimated* in its potential impact. The credit can yield more than 50% savings for data centres, significantly enhancing their environmental sustainability. The extent of this underestimation means that LEED's projected savings are considerably lower than what can be achieved. The overall effect of this underestimation is substantial, leading to 47% in of potential savings being overlooked (as shown in Table 5.11).

Proposed Adjustment

For renewable energy credit, the scoring system should be adjusted to incentivise not only the percentage of renewable energy used but also the strategies that maximise the usage of renewable energy, including hybrid solutions with on-site, off-site, and battery storage.

6.3.4 Material and Resources Environmental Credits Gaps Analysis

Within the LEED criteria, the Materials and Resources category focuses on construction and material usage during the building process, as well as waste disposal. This section addresses two critical credits: Building Life Cycle Impact Reduction and Construction and Demolition Waste Management. These credits aim to promote sustainable construction practices by reducing the environmental impact of materials used and efficiently managing waste during construction activities.

Building Life Cycle Impact Reduction

Intent

The intent of this credit is to adopt the reuse of existing building materials and reduce the environmental impacts of new construction by assessing and minimising the life cycle impacts of building materials. Requirements encourages conducting a life cycle assessment of project structure and enclosure, demonstrating a minimum 20% in Global Warming Potential.

Gaps

Similar to the Heat Island Reduction credit, there is a lack of comprehensive data and research specific to data centres. There is no established benchmark for baseline buildings for data centres, making accurate comparisons difficult. The dynamic nature of data centre operations, including the need for expansion and fluctuating capacity requirements, introduces complexities not encountered in other building types. Comparing data centres to standard office buildings for LCA purposes is challenging and often inaccurate due to their distinct structural designs, usage patterns, and differing weightings on infrastructure components.

Furthermore, the LCA in this credit primarily focuses on the building enclosure and construction, with no evidence of a systems perspective approach. This means it lacks a full life cycle perspective, missing the demolition phase and neglecting the operations phase. Consequently, accurately assessing and scoring data centres for LCA credits is currently hindered by these limitations, highlighting a key gap in evaluating their environmental impact.

Impact Level

The impact of this category is relatively *low impact* for data centres, as the majority of their environmental footprint arises from operational energy use rather than construction phase emissions. The impact presented is based on calculations. While variations in facility performance are possible, each data centre has different priorities to improve sustainability.

Score Alignment

Based on LEED scoring Scheme this credit is considered to be *overestimated.*

Proposed Adjustment

Developing more comprehensive benchmarks for data centre buildings is crucial. This includes creating baseline data specific to data centres, considering their unique operational and structural characteristics. Additionally, incorporating a systems perspective into the LCA approach is necessary. This should cover the full life cycle, including the demolition phase and operational phase impacts and include the equipment used in operation phase.

Construction and Demolition Waste Management

Intent

The intent of this credit is to reduce construction and demolition waste disposed of in landfills and incineration facilities by recovering, reusing, and recycling materials.

Gaps

No significant gaps were identified in the credit.

Impact Level

This credit has a relatively *low impact*.

Score Alignment

The credit is *overestimated* in the LEED scoring scheme.

Proposed Adjustment

No specific adjustments are recommended for this credit, except for revising the scoring and quantitative reflectance to better match its actual impact.

Category Adjustment

This proposal is not applicable to colocation data centres. LEED doesn't account for the substantial emissions from servers and IT equipment. For example, Dell reports that the carbon footprint of a single server is approximately 1,314 kg CO_2, which falls under scope 3 emissions (DELL, 2019)

Considering the Dell server with an energy demand of 1,760.3kWh, yielding to nearly 0.2 kW / server, we can estimate the number of servers required for an IT load of 500 kW (Case Study 1). This calculation leads to approximately 2,500 servers. Given that each server has a reported carbon footprint of 1,314 kg CO_2, the total Scope 3 emissions impact from these servers would amount to approximately 3,285 tonnes of CO_2. This substantial Scope 3 effect is not currently accounted for in the LEED certification practices.

An overall adjustment in Materials and Resources category is to include considerations for IT equipment and operational phase impacts, ensuring a more comprehensive assessment of data centre sustainability. Consider circularity and the use of second-life hardware. Extending hardware lifetimes through secondary markets can reduce the environmental impact by decreasing the volume of new hardware manufactured. Where possible, critical raw materials should be reclaimed at the end-of-life for reuse in new products, closing the materials loop and reducing supply chain criticality.

6.3.5 Other Credits

Other than the environmental credits impacting CO_2 emissions directly, an important environmental aspect is overlooked in LEED is water efficiency and usage in data centres. While there is a category for water efficiency, it focuses on indoor and outdoor water use. The credit associated with optimising the cooling system and chillers involves basic requirements. However, cooling systems play a huge role in water usage and are not adequately addressed in the criteria. This gap highlights the need for more detailed and specific water efficiency credits that reflect the significant water usage associated with cooling systems in data centres.

Nevertheless, there is an alternative path credit that can be taken, which accounts for a full decrease in water usage, applicable to facilities that do not have cooling towers. Yet, this is still challenging due to the gap in literature about water baseline usage in data centres. Addressing this gap and providing comprehensive guidelines for water efficiency in data centres could lead to significant environmental benefits and more effective resource management.

The next section presents a SWOT analysis for LEED in the context of assessing data centres, based on our data analysis.

6.4 SWOT Analysis

This section presents a Strength-Weakness-Opportunities-Threat (SWOT) analysis for LEED in the context of assessing data centres, based on our analysis. Table 6.3 summarises the strengths, weaknesses, opportunities, and threats related to the LEED framework and certification for data centres. This analysis aims to offer a balanced perspective on LEED's current framework and its applicability to the unique operational and sustainability challenges of data centres.

Positive	Negative
Strength	**Weakness**
• Continuous updates and improvements • Recognises data centres separately • Provides incentives through higher certification levels • Alternative path credit availability	• Lack of specific guidelines for data centres, treating them similar to other buildings • Misalignment between LEED scores and actual impact • Inaccurate certification levels reflections • Incentivising behaviour of approaching cost-effective practices but less impactful practices
Opportunities	**Threats**
• Growing market in data centre industry • Regulations driving data centres to environmental sustainability	• Lack of trust in LEED's ability to reflect data centre environmental sustainability • Emergence of more data centre dedicated certification schemes

Table 6.3 SWOT Analysis Summary for LEED Data Centre Framework and Certification

6.4.1 Strength

Continuous Updates and Improvements

Since its establishment, LEED has consistently undergone updates and improvements. It incorporates public comment periods to gather stakeholder input, which helps refine drafts into the latest versions (USGBC, 2024k).

Recognises Data Centres Separately

LEED has a separate certification for data centres, acknowledging their unique functions. This allows for specific updates to the data centre framework, facilitating tailored changes and improvements.

Provides Incentives Through Higher Certification Levels

The structure of higher certification levels and scores incentivises operators to implement and achieve environmental practices. This strategy encourages green building by offering financial and structural incentives, encouraging innovation and demand for green building technologies.

Alternative Path Availability

One of the notable strengths of the current LEED framework is the inclusion of an alternative path credit system. This system offers significant flexibility by allowing facilities to achieve full credits through diverse and innovative strategies.

6.4.2 Weaknesses

Lack of Specific Guidelines for Data Centres, Treating Them Similar to Other Buildings

Although LEED recognises data centres in a separate framework, it does not significantly differentiate them from other buildings, with 90% of credits being the same (Moud, et al., 2020). This approach misleads how savings and impacts are reflected and represented, assessing data centres with the same scoring reflectance as other buildings. It overlooks the best practices and standards specific to data centres, especially during the operational phase.

Scoring System Misalignment

The scoring system shows a misalignment between the scores and the actual savings and importance of credits for data centres. It overestimates low-impact credits and underestimates high-impact ones.

Inaccurate Certification Levels Reflections

A higher certification level, such as LEED Gold or Platinum, does not always equate to higher energy savings. This misalignment leads to inaccurate reflections of energy savings attributed to different certification levels. Consequently, stakeholders may be misled into believing that higher certification guarantees better performance, which is not always the case. This misalignment undermines the credibility of the certification system and can lead to misguided investments and efforts in sustainability practices.

Incentivising Behaviour to Approaching Cost-Effective Practices but Less Impactful Practices

There is a risk of operators adhering to lower-cost and easier credits that do not significantly decrease the environmental impact of data centres. Results show that the most achieved credits are those that are easier and lower in cost, which do not lead to higher environmental savings.

6.4.3 Opportunities

The Growing Demand

Trends and meta-analysis results show that more data centres are seeking LEED certification, expanding its influence in more regions. The growing data centre industry presents opportunities for LEED to enhance its impact.

Regulations Driving Data Centres to Environmental Sustainability

Rising regulations focused on environmental sustainability support enhancing LEED's relevance and effectiveness in this sector. Government incentives for achieving certifications can further drive this growth. Investment incentives play a crucial role, as they encourage data centres to pursue LEED certification by offsetting some of the associated costs. These incentives can include tax breaks, grants, and subsidies, making it financially viable for organisations to invest in sustainable practices. As a result, more data centres are likely to aim for higher certification levels, thereby promoting widespread adoption.

6.4.4 Threats

Lack of Trust in LEED's Ability to Reflect Data Centre Environmental Sustainability

The fact that LEED does not adequately consider data centres' unique characteristics and fails to reflect real savings and impacts in certification scores leads to a lack of trust among data centre operators regarding its applicability. The misalignment between scores and actual impact raises questions about LEED's validity. The possibility of achieving high certification levels with minimal savings undermines its credibility.

Emergence of More Data Centre Dedicated Certification Schemes

The proliferation of more dedicated certification schemes tailored specifically to data centres is a significant threat. These new schemes, such as EN 50600-5-2, offer more precise guidelines and standards that better address the unique needs and impacts of data centre operations compared to the more generalised approach of LEED. As a result, data centres might be more inclined to adopt these specialised certifications, potentially diminishing the relevance and appeal of LEED certification within this industry.

6.5 Conclusion

This chapter addresses the significant gaps in the existing LEED framework as applied to data centres, proposing a new, more tailored scoring system to better reflect the actual environmental performance of these specialised facilities. While LEED is a widely used certification system, it currently applies a uniform framework across all building types, which fails to capture the unique operational characteristics of data centres, such as their high energy consumption, cooling demands, and limited human occupancy.

The chapter begins by introducing a newly proposed scoring scheme specifically designed to reflect the environmental impact of data centres more accurately. This scheme is based on empirical data, drawn from actual case studies and operational performance, ensuring that the new scores are aligned with the realities of data centre sustainability. The proposed scoring scheme offers flexibility, allowing it to adapt to the different sizes, types, and regional grid intensities of data centres.

In the next sections, the chapter thoroughly reviews and refines the descriptions and criteria of individual LEED credits. These refinements ensure that the credits are more representative of data centre operations, and better reflect their environmental and operational challenges. For example, credits such as Access to Quality Transit and Bicycle Facilities are less relevant to data centres due to their limited occupancy, and adjustments are proposed to make these credits more applicable.

The chapter also highlights the importance of implementing multiple scoring schemes to accommodate the diversity of data centres, as one single criterion is not sufficient to capture the variety of environmental impacts associated with different types of facilities. This tailored approach addresses the discrepancies between LEED scores and actual savings, providing a more realistic and impactful certification system.

Finally, a SWOT analysis is presented to evaluate the current LEED framework in the context of data centres. This analysis identifies the strengths of LEED, such as its continuous updates and flexibility, while also highlighting its weaknesses, particularly the misalignment between certification scores and actual environmental impact. The opportunities and threats associated with enhancing LEED for data centres are also explored, with a focus on the growing demand for dedicated sustainability certification systems in the industry.

In conclusion, this chapter provides a comprehensive evaluation of the LEED framework for data centres, proposing significant amendments to ensure that the certification system better reflects the operational and environmental realities of these facilities. These proposed changes form the basis for the next chapter, which validates the new scoring system through the application to certified case studies, demonstrating the effectiveness and practicality of these amendments in real-world scenarios.

The next chapter validates that the new scores align with the actual impacts observed in data centres and apply this revised scoring to the certified case studies previously compared.

Chapter 7. Assessment and Verification of Proposed Score Effectiveness

7.1 Introduction

This chapter focuses on validating the proposed new scoring schemes, which aim to reflect the actual impact and efficacy of sustainable practices in data centres. The new scheme is compared to the impacts observed in previous case studies, providing a grounded analysis of its effectiveness and relevance. By comparing the environmental impact proportions of the five case studies discussed in Chapter 4 with their reflection in the new scoring allocations, this chapter aims to verify the effectiveness of the newly proposed scoring scheme for LEED certifications.

7.2 Alignment of New Scoring Scheme with Actual Savings Across Five Case Studies

This section confirms the alignment of the initial proposed scoring schemes and the necessity for multiple schemes. Figure 7.1 illustrates the alignment between the actual savings achieved by each case study and the new scoring scheme.

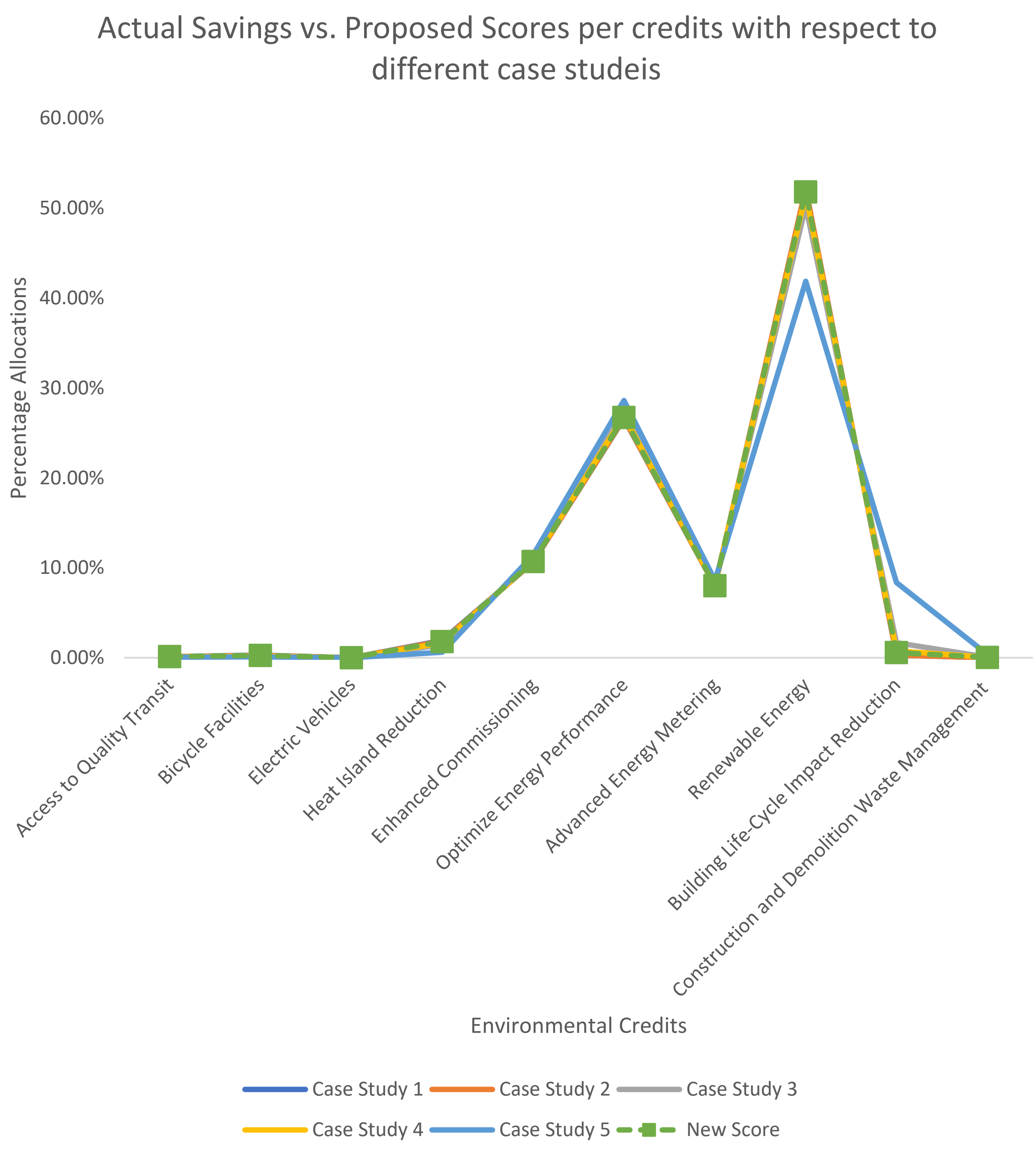

Figure 7.1 Aligning Proposed Scores with Real-World Environmental Impact Across Case Studies

The figure demonstrates the alignment of the proposed scoring scheme with real-world data, highlighting its effectiveness. However, some misalignment is noted in the renewable energy credit for low grid intensity Case 5. The extent of this discrepancy between the score and the actual impact in this case is quantitatively assessed and detailed in Table 7.1.

LEED Environmental Credits	Impact Metric (Case 5)
Access to Quality Transit	0%
Bicycle Facilities	0%
Electric Vehicles	0%
Heat Island Reduction	1%
Enhanced Commissioning	-1%
Optimise Energy Performance	-2%
Advanced Energy Metering	-1%
Renewable Energy	10%
Building Life-Cycle Impact Reduction	-8%
Construction and Demolition Waste Management	0%

Table 7.1 Absolute Error in Proposed Scores to The Actual Impact Of Case Study 5

This table indicates that the absolute value of discrepancy for the Renewable Energy credit is only 10%. The impact of this credit is significantly influenced by regional and locational factors, rather than intrinsic characteristics of the facility itself. Moreover, a value -8% showing an underestimation for the building life cycle impact reduction credit that focuses on the building construction phase impact. This misalignment can be attributed to the variability in facility performance and the different priorities for sustainability across facilities. For instance, a data centre using 100% renewable energy would exhibit lower operational impact, but higher embodied impact compared to a facility relying on a national electricity grid with minimal renewables.

While Case 5 shows some misalignment, the proposed scoring scheme generally aligns well with the majority of credits and other case studies, demonstrating its overall effectiveness.

The results verify and emphasise the need for flexibility in having more than one scoring scheme to accommodate the different natures and factors impacting savings in data centres.

The verification of the second scoring scheme, compared to case study 5, is presented in Figure 7.2.

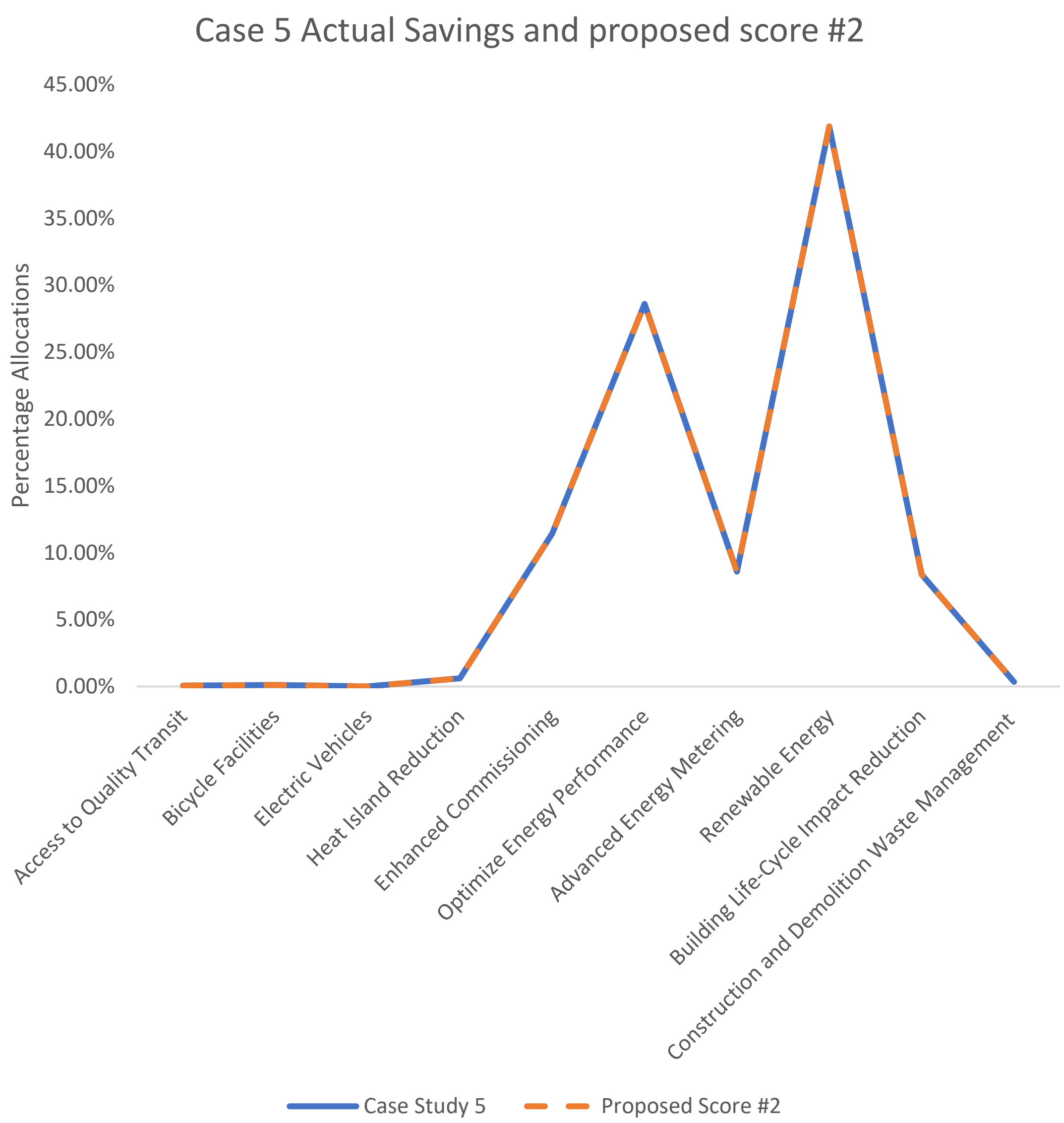

Figure 7.2 Aligning Proposed Scores # 2 with Real-World Environmental Impact Across Case Study 5

This figure demonstrates alignment with all credits, highlighting the effectiveness of having multiple scoring schemes to better reflect the unique characteristics and savings opportunities of each data centre.

7.3 Applying the New Scoring Scheme on LEED Certified Data Centres

To further demonstrate the effectiveness of the new scoring scheme in reflecting actual environmental impacts, it is applied to the Gold and Certified certifications profile previously studied. Applying the new score based on Table 6.1 for each credit based on their practices achieved is presented in Table 7.2.

LEED Environmental Credits	**Gold Score Case A**	**Certified Score Case B**
Access to Quality Transit	34	0
Bicycle Facilities	0	72
Electric Vehicles	1	0
Heat Island Reduction	523	0
Enhanced Commissioning	2,583	1,550
Optimise Energy Performance	2,583	7,749
Advanced Energy Metering	2,325	2,325
Renewable Energy	0	0
Building Life-Cycle Impact Reduction	167	0
Construction and Demolition Waste Management	4	4
Total	**8,219**	**11,699**

Table 7.2 New Scores for Certified Facilities

The proposed new scores for certified facilities in Table 7.2 are calculated by multiplying the revised scores listed in Table 6.1 by the percentages calculated in Table

5.12. This method adjusts the scores to better reflect the actual environmental impact and contributions of each credit.

For example, for the Enhanced Commissioning credit, if the new score in Table 6.1 is 3100 and the percentage of actual savings for the certified profile if calculated in Table 5.12 is 50%, the new score for this credit would be calculated as:

$$3{,}100 \times 50\% = 1{,}550 \text{ for the certified profile.}$$

The results show that certifications with higher environmental savings now achieve correspondingly higher scores. The outcomes indicate a significant enhancement in how scores mirror actual environmental impacts compared to the previous scoring system. Overall, the new scoring schemes offer a tailored approach, ensuring more accurate and meaningful evaluations for data centres.

7.4 Conclusion

This chapter validates the newly proposed scoring schemes by comparing them against actual environmental impacts observed in case studies. The analysis highlights the importance of developing multiple scoring schemes, as a single, uniform scoring system does not align effectively with the diverse nature of data centres. Differences in size, location, and operational practices significantly affect the environmental savings of each facility, making it clear that flexibility in scoring is essential.

The findings suggest that a tailored approach, which takes into account the specific characteristics and sustainability efforts of each data centre, offers a more accurate reflection of their environmental performance. In particular, the results show that certifications based on higher environmental savings achieve correspondingly higher scores, validating the relevance and effectiveness of the new scoring system.

Overall, this chapter confirms that the proposed scoring schemes provide a more accurate and meaningful assessment of data centre sustainability, addressing the shortcomings of the current LEED framework. The flexibility of the new system ensures that the unique operational and environmental challenges of data centres are better represented, enhancing the overall effectiveness of sustainability certification.

Chapter 8. Conclusion

8.1 Recap and Key Findings

The analysis of LEED certification attainment patterns for data centres shows significant growth, particularly from 2020 onwards, with a peak observed in 2023. China leads in the number of LEED-certified data centres, with many data centre providers aiming to achieve LEED certification for all their new facilities.

The most commonly attained credits are those that are easier and less costly to achieve, even if they do not result in substantial or high savings. This trend highlights a preference for credits that are more accessible rather than those that provide significant environmental benefits.

Applying the proposed model to several case studies of data centres of varying sizes and locations revealed that energy credits, particularly those related to renewable energy, contribute the most to overall savings. Renewable energy credits alone can account for more than 50% of the total savings by offsetting fossil fuel impacts. However, the results also demonstrate that each data centre's unique characteristics lead to different savings contributions, confirming that a uniform approach does not work effectively for data centres.

The findings indicate that current LEED-certified data centres may not truly reflect actual savings in line with higher certification levels, raising concerns about potential greenwashing. Therefore, a proposal for a new categorised scoring scheme or weighted approach is recommended. Additionally, LEED requirements and best practices should be more tailored to the specific needs of data centres, as seen in other standards such as EN 50600.

The newly proposed scheme, when applied to currently certified data centres, better reflects actual savings and environmental impact. This tailored approach ensures that LEED certification is more accurate and meaningful, promoting genuine sustainability in the data centre industry.

8.2 Limitation

This study acknowledges several limitations inherent in the modelling approach and analysis, which are important for the interpretation and applicability of the results.

Firstly, the model evaluates each credit independently, without considering the cumulative effects or interactions between multiple credits. For example, achieving a 50% improvement in energy efficiency sets a new baseline for further savings from renewable energy integration, potentially enhancing overall energy reduction and emissions savings. However, the model does not account for these overlapping effects, focusing solely on the individual effectiveness of each credit. This limitation means that potential synergistic benefits from combined credit implementation are not reflected in the results. However, this was not an issue for the type of analysis conducted in this study.

Secondly, the model used in this research is designed to calculate the potential environmental impact opportunities from LEED credits. However, LEED does not consider IT operations or the computational element of data centres in its assessment criteria. While this gap is addressed in Chapter 6, it was not included in the model, as the focus was on aligning with LEED's best practice guidelines. The computational aspect remains outside the scope of the LEED framework and, therefore, of this study's model.

Thirdly, the model uses arithmetic averages to show the opportunity savings across different case studies. The averages used are the ones corresponding to the normalised savings. This approach could skew results towards the case study with the largest energy consumption or grid intensity. On the other hand, when averaging opportunity savings (tonnes of CO_2), the results may disproportionately reflect the largest energy consumer, such as case study 5. Conversely, normalised results may align more with case studies 1 and 2, which have higher grid intensities. The discrepancies are presented using the average per IT load kW since it aligns with most of our case studies. While this method helps to identify discrepancies, it may not fully capture the diversity of impacts and opportunities across different types and locations of data centres.

Fourthly, the Heat Island Reduction credit's effectiveness in terms of savings percentage is applicable in hot climates, and further research is required to assess its impact in other climates and case studies. This limitation suggests that the benefits observed may not be universally applicable and need to be evaluated under different environmental conditions

Finally, the analysis excludes the Demand Response/Grid Harmonisation credit, as it primarily contributes to savings in power plant capacity and overall emissions reduction, rather than direct energy savings or emissions reductions within the data centre. Demand response programmes aim to reduce or shift electricity usage during peak demand periods, stabilising the grid and lowering emissions by reducing reliance on less efficient power plants. While these benefits are significant for the electrical grid and environment, they do not directly impact the energy consumption or emissions metrics specific to data centre operations. Although the selected credits were inclusive of various factors, some environmental credits that do not directly impact CO_2 emissions or data centres were excluded. For example, water usage reduction credits were not considered.

These limitations highlight areas for future research to consider cumulative effects, more nuanced averaging methods, and the inclusion of broader credits to provide a comprehensive understanding of energy savings and emissions reductions in data centres.

8.3 Further Research

This research focused on addressing gaps in LEED and calculating potential impact opportunities using LEED criteria. It introduced a new scoring scheme that considers different categories for assessing sustainability performance.

First, future work will involve raising awareness about how to identify better savings opportunities through LEED certification, both within and beyond the scope of this research. This includes aligning with data centre-specific best practice guidelines, such as EN 50600, to incorporate water efficiency best practices for cooling systems.

Second, within the scope of this research, further studies will aim to expand the categories by considering specific environments, types, and workloads for data centres. Additionally, further exploration and application of a weighted scoring criteria system will be essential to evaluate its practicality and effectiveness.

Third, collaboration with USGBC advisory committees and technical advisory groups (TAGs) will be key in addressing identified gaps and aligning LEED criteria with the real-world impacts of data centres. Communicating with the advisory committee will make LEED data centre certification more reflective of operational realities and environmental performance.

Moreover, implementing these amendments and models will require gaining acceptance from stakeholders, including policymakers, data centre operators, and the wider community. Policy and financial incentives should extend beyond certification levels to assess specific credits, applying the model from this research to fully capture impact opportunities and provide a complete view of the criteria's application. However, challenges may arise, as policymakers may find it difficult to integrate new schemes into existing regulations, and data centre operators could resist changes due to costs. Limited public awareness of the importance of these sustainability measures could also hinder broad support. Overcoming these barriers will require future efforts to focus on enhancing stakeholder engagement, aligning policy frameworks, and improving communication about the environmental impacts of data centres.

Finally, future research should adopt a similar methodology to examine emerging certification schemes, such as EN 50600-5-2, which are gaining industry attention. Analysing these schemes will help identify best practices and integrate them into existing frameworks, ensuring a more comprehensive and effective approach to sustainability certification for data centres.

References

Abraham, Y., Greenwood, L., Andoh, N.-Y. & Schneider, J., 2022. Sustainable Building without Certification: An Exploration of Implications and Trends. *Hapres: Journal of Sustainability Research.*

Adekanye, O., Davis, A. & Azevedo, I. L., 2020. Federal policy, local policy, and green building certifications in the U.S.. *Elsevier,* 209(109700).

ADIB, 2023. *Abu Dhabi Bank Sustainable Finance Framework,* Abu Dhabi: Abu Dhabi Islamic Bank.

Algarni, S., 2018. Potential for cooling load reduction in residential building using cool roofs in the harsh climate of Saudi Arabia. *Sage: Energy & Environment.*

Anderson, J. Q., 2005. 1960s – 1990s: Internet. In: *Imagining the Internet: Personalities, Predictions, Perspectives,.* North Calorina: Rowman & Littlefield.

ARC, 2019. *What is the carbon footprint of a LEED-certified building?.* [Online] Available at: https://arc.gbci.org/what-carbon-footprint-leed-certified-building

AutoSmart, 2014. *Learn the facts: Emissions from your vehicle,* Canada: Natural Resources Canada.

AWS, 2006. *Announcing Amazon Elastic Compute Cloud (Amazon EC2).* [Online] Available at: https://aws.amazon.com/about-aws/whats-new/2006/08/24/announcing-amazon-elastic-compute-cloud-amazon-ec2---beta/#

Bashroush, R., 2018. *Supporting the innovation of public procurement for environmentally sound data center products and services - Final Report,* London: EURECA - Datacenter EURECA Project.

Bashroush, R., Rteil, N., Kenny, R. & Wynne, A., 2020. Optimzing server refresh cycles: The case for circular economy with an againg Moore's Law. *IEEE Transactions on Sustainable Computing,* 7(1), pp. 189-200.

Bashroush, R., Wood, E. & Noureddine, A., 2016. Data center energy demand: What got us here won't get us there,". *IEEE Software,* Volume 33, pp. 18-21.

Basten, V., Latieg, Y., Berawi, M. A. & Crevits, I., 2018. Building Incentive Structure in the Context of Green Building Implementation: From the Local Government Perspective. *Journal of Design and Built Enviroment,* 8(2).

Bondareva, E., 2007. Green Star-LEED's Australian Cousin. *Journal of Green Building,* 1 August, 2(3), pp. 32-40.

BRE, 2019. *Data Centres , The Sustainability Gaps.* London: BRE.

BREEAM, 2012. *BREEAM Data Centres 2010.* [Online]
Available at:
https://tools.breeam.com/filelibrary/Technical%20Manuals/SD5068_1_2_BREEAM_Datacentres_2010.pdf

BSI, 2022. *Informtaion technology - Data Centre Faciltities and Infrastructure Part 4-9: Water Usage Effectiveness,* London: British Standards Institution.

BSI, 2024. *BSI 50600.* [Online]
Available at: https://knowledge.bsigroup.com/products/information-technology-data-centre-facilities-and-infrastructures-general-concepts?version=tracked
[Accessed 2024].

Cai, S. & Gou, Z., 2023. A comprehensive analysis of green building rating systems for data centers. *Energy and Buildings,* Volume 284.

Central Committee of the Communist Party of China, 2016. *THE 13TH FIVE-YEAR PLAN FOR ECONOMIC AND SOCIAL DEVELOPMENT OF THE PEOPLE'S REPUBLIC OF CHINA,* Beijing: s.n.

Claridge, D. E., Culp, C. H. & Liu, M., 2000. Campus-Wide Continuous Commissioining of University Buildings. *Commercial Buildings: Technologies, Design, and Performance Analysis.*

Clark, D. & Reed, D., 1978. An introduction to local area network. *IEEE,* 66(11), pp. 1497-1517.

Climate Transparency, 2022. *Saudi Arabia,* Berlin: Climate Transparency.

Coyne, B., Denny, E. & Fitiwi, D. Z., 2023. The benefits of low-carbon energy efficiency technology adoption for data centres. *Energy Conversion and Management:X.*

Crippa , M. et al., 2022. *CO2 emissions of all world countries JRC/IEA/PBL 2022 Report,* s.l.: Publications Office of the European Union, Luxembourg.

Danske, 2022. *Green fiannce Framwork,* Copenhagen: Danske Bank.

DCD, 2024. *Certifying Best Practices | Improving Performance.* [Online]
Available at: https://www.datacenterdynamics.com/en/ceeda/

DEEP, 2024. [Online]
Available at: https://datacenterevolve.com/certified-data-centers

DELL, 2019. *PowerEdge R640,* Round Rock, TX: DELL.

Denzer, A. & Hedges, K. E., 2011. The Limitations of LEED: A Case Study. 6(1).

Digital Realty, 2021. *A brief history of data centres.* [Online]
Available at: https://www.digitalrealty.co.uk/resources/articles/a-brief-history-of-data-centers

DLAPiper, 2023. *Part 2: Energy Efficiency Act – New legal requirements for data centres,* Germany: DLA piper.

DST, 2024. *Climate Change Program.* [Online]
Available at: https://dst.gov.in/climate-change-programme

Dubai Islamic Bank, 2022. *Suatainable Finance Framework,* Dubai: Dubai Islamic Bank.

EEA, 2021. *Transport and environment report 2021 Decarbonising road transport — the role of vehicles, fuels and transport demand,* s.l.: s.n.

EERE, 2013. *Data Center and Servers.* [Online]
Available at: https://www.energy.gov/eere/buildings/data-centers-and-servers
[Accessed 2024].

EERE, 2023. *How Wind Can Help Us Breathe Easier.* [Online]
Available at: https://www.energy.gov/eere/wind/articles/how-wind-can-help-us-breathe-easier

Electric Vehicle Database, 2024. *Energy consumption of electric vehicles,* s.l.: EV database.

EMBER, 2023. *China led in wind and solar generation globally in 2023, while also ranking as the world's largest power sector emitter,* s.l.: EMBER Climate.

EMBER, 2024. *European Electricity Review 2024,* s.l.: EMBER climate.

EPA, 2016. *Clean Power Plan for Existing Power Plants: Regulatory Actions.* [Online]
Available at: https://archive.epa.gov/epa/cleanpowerplan/clean-power-plan-existing-power-plants-regulatory-actions.html

EPA, 2023. *Previous Sustainability Requirements.* [Online]
Available at: https://www.epa.gov/greeningepa/previous-sustainability-requirements

EPA, 2024. *Overview of the Renewable Fuel Standard Program.* [Online]
Available at: https://www.epa.gov/renewable-fuel-standard-program/overview-renewable-fuel-standard-program

ETHW, 2019. *Rise and Fall of Minicomputers.* [Online]
Available at: https://ethw.org/Rise_and_Fall_of_Minicomputers

EU Commission, 2012. *Environmental Impact Assessment,* Brussels: Eur-Lex.

EU Commission, 2014. *Regulation (EU) No 517/2014.* [Online]
Available at: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=celex%3A32014R0517
[Accessed 2024].

EU Commission, 2015. *2020 Climate and Energy Package.* Brussels: Eur-Lex.

EU Commission, 2021. *Green Public Procurement Criteria and Requirement.* [Online]
Available at: https://green-business.ec.europa.eu/green-public-procurement/gpp-criteria-and-requirements_en
[Accessed 2024].

EU Commission, 2022a. *Green cloud and green data centres.* Brussels: Eur-Lex.

EU Commission, 2022b. *Study on new mobility patterns in European cities.* Brussels: Eur-Lex.

EU Commission, 2023a. *What is EU ETS?.* [Online]
Available at: https://climate.ec.europa.eu/eu-action/eu-emissions-trading-system-eu-ets/what-eu-ets_en
[Accessed 2024].

EU Commission, 2023b. *Circular Economy Action Plan.* [Online]
Available at: https://environment.ec.europa.eu/strategy/circular-economy-action-

plan_en#:~:text=The%20new%20action%20plan%20announces,for%20as%20long%20as%20possible.
[Accessed 2024].

EU Commission, 2023c. *EU taxonomy of Sustainable Activities.* [Online]
Available at: https://finance.ec.europa.eu/sustainable-finance/tools-and-standards/eu-taxonomy-sustainable-activities_en
[Accessed 2024].

EU Commission, 2023d. *Reporting requirements on the energy performance and sustainability of data centres for the Energy Efficiency Directive. Task A report, Options for a reporting scheme for data centres,* Brussels: Eur-Lex.

EU Commission, 2023e. *Green Public Procurement.* [Online]
Available at: https://green-business.ec.europa.eu/green-public-procurement_en
[Accessed 2024].

EU Commission, 2024a. *REPowerEU.* [Online]
Available at: https://commission.europa.eu/strategy-and-policy/priorities-2019-2024/european-green-deal/repowereu-affordable-secure-and-sustainable-energy-europe_en#repowereu-at-a-glance
[Accessed 2024].

EU Commission, 2024b. *Energy Efficiency Directive.* [Online]
Available at: https://energy.ec.europa.eu/topics/energy-efficiency/energy-efficiency-targets-directive-and-rules/energy-efficiency-directive_en
[Accessed 2024].

EU Commission, 2024c. *Fit for 55.* [Online]
Available at: https://www.consilium.europa.eu/en/policies/green-deal/fit-for-55/
[Accessed 2024].

EU Commission, 2024d. *Energy Efficiency Directive.* [Online]

Available at: https://energy.ec.europa.eu/topics/energy-efficiency/energy-efficiency-targets-directive-and-rules/energy-efficiency-directive_en

[Accessed 2024].

European Union Law, 2023. *Directive (EU) 2023/1791,* Brussels: Eur-Lex.

Fakhim, B., Behnia, M., Armfield, S. & Srinarayana, N., 2011. Cooling solutions in an operational data centre: A case study.. *Applied Thermal Engineering,* 31(14-15), pp. 2279-2291..

Federal Ministry for Economic Affairs and Climate , 2024. *Guide to the data points in the data centre register,* Berlin: Federal Ministry for Economic Affairs and Climate Action (BMWK).

Flucker, S., Whitehead, B. & Tozer, R., 2018. Data Centre Sustainability Beyond Energy Efficiency. *Building Services Engineering Research & Technology.*

Forti, V., Balde, C. P., Kuehr, R. & Bel, G., 2020. *The Global E-waste Monitor 2020: Quantities, flows and the circular economy potential.* s.l.:United Nations University/United Nations Institute for Training and Research, International Telecommunication Union, and International Solid Waste Association.

Fujian Gov, 2021. *Outline of the 14th Five-Year Plan (2021-2025) for National Economic and Social Development and Vision 2035 of the People's Republic of China.* [Online]

Available at: https://www.fujian.gov.cn/english/news/202108/t20210809_5665713.htm

GDS, 2022. *Eight GDS Data Centers Receive LEED Gold Certification by Benchmarking Against Global Green Building Standards.* s.l.:s.n.

GHG Protocol, 2004. *A Corporate Accounting and Reporting Standard,* Washington,DC: World Resources Institute and World Business Council for Sustainable Development.

GIZ, 2022. *National New Data Centre Development,* Eschborn: GIZ (Deutsche Gesellschaft für Internationale Zusammenarbeit).

Government of Ireland, 2021. *Irish GPP Criteria: ICT Products and Servers,* s.l.: s.n.

Holmes, S., 2022. *LEED hits 100,000 certified projects.* [Online] Available at: https://www.usgbc.org/articles/leed-hits-100000-certified-projects

IEA, 2019. *Saudi Arabia Corporate Average Fuel Economy (CAFE) standards.* [Online] Available at: https://www.iea.org/policies/8395-saudi-arabia-corporate-average-fuel-economy-cafe-standards

IEA, 2021. *Global EV Outlook 2021,* Pairs: IEA.

IEEE Spectrum, 2023. *Ethernet is Still Going Strong After 50 Years.* [Online] Available at: https://spectrum.ieee.org/ethernet-ieee-milestone#:~:text=Ethernet%20wired%20LAN%20was%20invented,the%20IEEE%20802.3%2D1985%20Standard.

IEEE, 2021. *The 1980s.* s.l.:IEEE Computer Society and History.

Industry ARC, 2024. *Data Center Market - Forecast(2024 - 2030),* s.l.: s.n.

ISO, 2021. *ISO 22237-1.* [Online] Available at: https://www.iso.org/obp/ui/en/#iso:std:iso-iec:22237:-1:ed-1:v1:en

JLL, 2023. *Unleashing the Potential: The Future of Data Centres in The Middle East and Africa,* s.l.: JLL.

JLL, 2024. *Getting data centers ready for the AI boom.* [Online]
Available at: https://www.jll.co.uk/en/trends-and-insights/workplace/getting-data-centers-ready-for-the-ai-boom

JRC/IEA, 2023. *GHG Emission of All world Countries,* Brussels: European Commission Joint Researc Centre.

KSA Government, 2024. *Saudi Arabia Vision 2030.* Riyadh: Government of Saudi Arabia (Vision 2030 Initiative).

KSTAR, 2020. *A Short History of Container Modular Data Center.* [Online]
Available at: https://www.kstar.com/review/17899.jhtml

Lawrence National Laboratory , 2017. *Speed is the Game,* Livermore,CA: Lawrence Livermore National Laboratory.

Li, G. et al., 2023. China's green data center development:Policies and carbon reduction technology path. *Elsevier BV,* Volume 231, pp. 116248-116248.

Liu, H. et al., 2023. *The Carbon Brief Profile: China.* [Online]
Available at: https://interactive.carbonbrief.org/the-carbon-brief-profile-china/#paris-pledge
[Accessed 4 April 2024].

Lltas, C., 2011. A model for quantifying construction waste in projects according to the European waste list. *Waste Management,* Issue 0956-053X, pp. 1261-1276.

Ma, J. & Cheng, J. C., 2016. Data-driven study on the achievement of LEED credits using percentage of average score and association rule analysis. *Elseveir,* Volume 93, pp. 121-132.

Mazhar, M. S., 2019. Comparative Study of WAN Services and Technologies in Enterprise Business Networks. *International Journal of Computer Science and Telecommunications,* 10(3).

Meta, 2024. *Sustainability Report 2024,* Menlo Park,CA: Meta.

METI, 2021. *Japan's Roadmap to "Beyond-Zero" Carbon.* [Online]
Available at:
https://www.meti.go.jp/english/policy/energy_environment/global_warming/roadmap/#:~:text=The%20third%20and%20most%20ambitious,Carbon%20Neutral%20in%2030%20years.

METi, 2022. *Energy Efficiency Judgment Guidelines for Factories and Business Sites,* Tokyo: Ministry of Economy,Trade and Industry(METI).

Microsoft, 2024. *How can we advance sustainability?,* Remond,WA: Microsoft.

Microsoft, 2024. *Microsoft Datacenters,* Redmond,WA: Microsoft Corporation.

Mitsubishi, 2023. *Newly developed "rack-type liquid immersion cooling system" that can be installed in existing data centers.* [Online]
Available at: https://www.mhi.com/jp/news/23061601.html

Moud, H. I. et al., 2020. Sustainability Assessment of Data Centers Beyond LEED. *IEEE Green Technologies Conference(GreenTech),* April.pp. 62-64.

Murino, T. et al., 2023. Sustainable Energy Data Centres: A Holistic Conceptual Framework for Design and Operations. *Energies,* Volume 16, pp. 5764-5764.

Nadjahi, C., Louahlia, H. & Lemasson, S., 2018. A review of thermal management and innovative cooling strategies for data center,. *Sustainable Computing: Informatics and Systems,* Volume 19, pp. 14-28.

Net Zero Climate, 2024. *What is net zero?.* [Online]

Available at: https://netzeroclimate.org/what-is-net-zero-2/

NSW Government, 2024. *NSW Climate and Energy Action.* [Online]

Available at: https://www.energy.nsw.gov.au/business-and-industry/programs-grants-and-schemes/supporting-business-decarbonise/metering-and

NTT - London 2 Data Center (2022) NTT.

Oakley, N., 2021. *The Evolution of Data Centers.* [Online]

Available at: https://storymaps.arcgis.com/stories/a21d93abf29d4b6990370cfcba143cd9

Open Compute Project, 2011. *Our history: Outgrowing traditional infrastructure.* [Online]

Available at: https://www.opencompute.org/about

Oro, E., Depoorter, V., Garcia, A. & Salom, J., 2015. Energy efficiency and renewable energy integration in data centres. Strategies and modelling review. *Renewable and Sustainable Energy Reviews,* Volume 42, pp. 429-445.

Owens, B., Macken, C., Rohld, A. & Rosenberg, H., 2013. *LEED v4: Impact Category and Point Allocation Development Process.* s.l.:s.n.

Owens, B., Macken, C., Rohloff, A. & Rosenberg, H., 2013. *LEED v4 Impact category and point allocation development process.* s.l.:s.n.

Polaris Market Research , 2024. *Green Data Center Market Share, Size, Trends, Industry Analysis Report, By Component (Solution, and Services); By Size of Enterprise; By End-Use Industry; By Region; Segment Forecast, 2024- 2032,* s.l.: s.n.

Prateek, J., 2017. *A Closer Look at How LEED Buildings Achieved Sustainability.* s.l., s.n.

Precedence Research, 2023. *Hyperscale Data Center Market,* Canada/India: Precedence Research.

Prescient & Strategic Intelligence, 2024. *Data Center Market Size & Share Analysis - Trends, Drivers, Competitive Landscape, and Forecasts (2024 - 2030),* s.l.: Prescient & Strategic Intelligence;.

Qatar GCO, 2024. *Qatar National vission 2030.* [Online]
Available at: https://www.gco.gov.qa/en/about-qatar/national-vision2030/

Qatar Government, 2024. *Qatar National Vision 2030.* Qatar: Governmnet.

Renogy UK, 2022. *Average Solar Panel Output Per Day: UK Guide.* [Online]
Available at: https://uk.renogy.com/blog/average-solar-panel-output-per-day-uk-guide/#:~:text=Average%20solar%20panel%20output%20per%20square%20metre&text=So%2C%20for%20a%2016%20panel,0.6kWh%20to%200.8kWh.

RIBA, 2021. *RIBA 2030 Climate Challenge,* London: RIBA.

RICS, 2015. *Going for Green: Sustainable Building Certification Statistics.* s.l.:Royal Institution of Chartered Surveyors (RICS).

Ristic, B., Madani, K. & Makuch, Z., 2015. The Water Footprint of Data Centers. *Multidisciplinary Digital Publishing Institute,* August, 7(8), pp. 11260-11284.

Ristic, B., Madani, K. & Makueh, Z., 2015. The Water Footprint of Data Centers. *Sustainability,* 7(8).

Schneider, 2011. *Calculating Total Power Requirements for Data Centers.* s.l.:Schneider.

Science Media and Museum, 2020. *A SHORT HISTORY OF THE INTERNET.* [Online]
Available at: https://www.scienceandmediamuseum.org.uk/objects-and-stories/short-history-internet

SEAi, 2022. *SEAI takes a closer look at the datasets highlighting data centre demand and renewable energy generation in Ireland..* Dublin: Sustainable Energy Authority of Ireland (SEAI).

Sears, J., Roberts, D. & Glitman, K., 2014. A comparison of electric vehicle Level 1 and Level 2 charging efficiency. *IEEE Conference on Technologies for Sustainability (SusTech),* pp. 255-258.

Sharma, R. et al., 2009. *Water efficiency management in datacenters: Metrics and methodology.* Piscataway, NJ, IEEE, pp. 1-6.

Smart Energy Decision, 2017. *Microsoft commits to LEED Gold for data centers.* [Online]
Available at: https://www.smartenergydecisions.com/energy-management/2017/11/20/microsoft-commits-to-leed-gold-for-data-centers

SPC, 2024. *Standards,* Beijing: Supreme People's.

Statista, 2023. [Online]
Available at: https://www.statista.com/statistics/610566/total-annual-sunshine-hours-uk/#:~:text=The%20total%20number%20of%20sunshine,had%20nearly%201%2C538%20sunshine%20hours.

STT GDC, 2021. *Carbon-neutral by 2030 and LEED Gold data centres – STT GDC goes green* [Interview] (November 2021).

SUN Microsystem, 2008. *Sun™ Modular Datacenter S20/D20,* Redwood Shores,CA: Oracle Corporation.

U.S Department of Energy , 2023. *INFLATION REDUCTION ACT OF 2022.* Washington,DC: U.S Department of Energy.

U.S DOE, 2016. *2016 Strategic Sustainability Performance Plan,* Washington,DC: U.S. Department of Energy.

U.S DOE, 2021. *The Current State of the Data Center Optimization Initiative,* Washington,DC: U.S. Department of Energy.

U.S. Department of State, 2019. *On the U.S. Withdrawal from the Paris Agreement.* [Online]
Available at: https://2017-2021.state.gov/on-the-u-s-withdrawal-from-the-paris-agreement/

U.S. Department of State, 2021. *The United States Officially Rejoins the Paris Agreement.* Washington,DC: U.S Department of State.

U.S. Department of Treasury, 2023. *FACT SHEET: How the Inflation Reduction Act's Tax Incentives Are Ensuring All Americans Benefit from the Growth of the Clean Energy Economy.* Washington,DC: U.S. Department of the Treasury.

U.S. EPA, 2016. *2016 Strategic Sustainability Performance Plan,* Washington,DC: U.S. Environmental Protection Agency (EPA).

UAE Government, 2024. *UAE Energy Strategy 2050.* [Online]
Available at: https://u.ae/en/about-the-uae/strategies-initiatives-and-awards/strategies-plans-and-visions/environment-and-energy/uae-energy-strategy-2050

UAE Government, 2024. *UAE Nationa Agenda.* Abu Dhabi: UAE Cabinet.

UNDP, 2022. *Online services reduce CO2 emissions from Saudi cars with some 0.77 million tons annually.* Riyadh: United Nations Development Programme (UNDP).

UNFCC, 2023. *Global Net Zero Commitments,* s.l.: United Nations Framework Convention on Climate Change .

UNFCCC, 2015. *The Paris Agreement: What is the Paris Agreement?,* Bonn: UNFCCC.

Urblik, L., Kajati, E., Papcun, P. & Zolotova, I., 2023. A Modular Framework for Data Processing at the Edge: Design and Implementation. *Sensors.*

US EPA, 1970. *NEPA,* Washington, DC: U.S EPA.

US EPA, 1990. *Clean Air Act Overview.* [Online]
Available at: https://www.epa.gov/clean-air-act-overview/1990-clean-air-act-amendment-summary#:~:text=promotes%20energy%20conservation%20through%20an,encourage%20customers%20to%20conserve%20energy.

US EPA, 1994. *Significant New Alternatives Policy (SNAP) Program.* [Online]
Available at: https://www.epa.gov/snap/regulations-proposed-rules-and-final-rules-determined-epa

USGBC Policy Library, 2024. *USGBC Policy Library.* [Online]
Available at: https://public-policies.usgbc.org/policies
[Accessed 2024].

USGBC, 2019. *U.S. Green Building Council Announces Top 10 Countries and Regions for LEED Green Building.* [Online]
Available at: https://www.usgbc.org/articles/us-green-building-council-announces-top-10-countries-and-regions-leed-green-building
[Accessed 2024].

USGBC, 2022. *USGBC announces Top 10 Countries and Regions for LEED in 2021.* [Online]
Available at: https://www.usgbc.org/articles/usgbc-announces-top-10-countries-and-regions-leed-2021

USGBC, 2023. *The Top 10 Countries for LEED demonstrate that green building is a truly global movement.* [Online]

Available at: https://www.usgbc.org/articles/top-10-countries-leed-demonstrate-green-building-truly-global-movement
[Accessed 2024].

USGBC, 2024. [Online]
Available at: https://www.usgbc.org/credits?Rating+System=%22Data+centers+-+New+Construction%22

USGBC, 2024. *Applying LEED to data center projects.* [Online]
Available at: https://support.usgbc.org/hc/en-us/articles/12154267763987-Applying-LEED-to-data-center-projects#advantages

USGBC, 2024a. *Projects.* [Online]
Available at: https://www.usgbc.org/projects?Rating+System=%5B%22Data+centers+-+New+Construction%22%5D&Certification=%5B%22Platinum%22%2C%22Gold%22%2C%22Silver%22%2C%22Certified%22%5D

USGBC, 2024b. *LEED project directory.* Washington,DC: USGBC.

USGBC, 2024b. *The Top 10 Countries for LEED in 2023 demonstrate that the green building movement is truly global.* [Online]
Available at: https://www.usgbc.org/articles/top-10-countries-leed-2023-demonstrate-green-building-movement-truly-global

USGBC, 2024c. *USGBC Project Profiles.* [Online]
Available at: https://www.usgbc.org/projects?Rating+System=%5B%22Data+centers+-+New+Construction%22%5D&Country=%5B%22Saudi+Arabia%22%5D
[Accessed 2024].

USGBC, 2024d. *LEED credit library.* [Online]
Available at:

https://www.usgbc.org/credits?Category=%22Location+%26+transportation%22
[Accessed 2024].

USGBC, 2024e. *LEED credit library.* [Online]
Available at:
https://www.usgbc.org/credits?Category=%22Sustainable+sites%22&Rating+System=%22Data+centers+-+New+Construction%22&Version=%22v4%22
[Accessed 2024].

USGBC, 2024f. *LEED credit library.* [Online]
Available at:
https://www.usgbc.org/credits?Category=%22Water+efficiency%22&Rating+System=%22Data+centers+-+New+Construction%22&Version=%22v4%22
[Accessed April 2024].

USGBC, 2024g. *LEED credit library.* [Online]
Available at:
https://www.usgbc.org/credits?Category=%22Energy+%26+atmosphere%22&Rating+System=%22Data+centers+-+New+Construction%22&Version=%22v4.1%22

USGBC, 2024h. *LEED credit library.* [Online]
Available at:
https://www.usgbc.org/credits?Category=%22Material+%26+resources%22&Rating+System=%22Data+centers+-+New+Construction%22&Version=%22v4.1%22

USGBC, 2024i. *LEED credit library.* [Online]
Available at:
https://www.usgbc.org/credits?Category=%22Indoor+environmental+quality%22&Rating+System=%22Data+centers+-+New+Construction%22&Version=%22v4.1%22

USGBC, 2024j. *LEED Rating System.* [Online]
Available at: https://www.usgbc.org/leed

USGBC, 2024k. *LEED v5 public comment.* [Online]
Available at: https://www.usgbc.org/leed/v5

Virk, G. et al., 2015. Microclimatic effects of green and cool roofs in London and theirimpacts on energy use for a typical office building. *Elsevier :Energy and Building,* pp. 214-228.

Vision 2030, 2016. *A story of Transformation.* [Online]
Available at: https://www.vision2030.gov.sa/en/vision-2030/story-of-transformation/

Vision 2030, 2021. *PUBLIC INVESTMENT FUND PROGRAM.* [Online]
Available at: https://www.vision2030.gov.sa/en/vision-2030/vrp/public-investment-fund-program/

Visual Capitalist, 2021. *Race to Net Zero: Carbon Neutral Goals by Country.* [Online]
Available at: https://www.visualcapitalist.com/sp/race-to-net-zero-carbon-neutral-goals-by-country/

W.media, 2024. *New Data Center Services Regulations come into force in Saudi Arabia.* [Online]
Available at: https://w.media/new-data-center-services-regulations-come-into-force-in-saudi-arabia/

Wadanambi, R. T. et al., 2020. The effects of industrialization on climate change. *JOURNAL OF RESEARCH TECHNOLOGY AND ENGINEERING,* Octo ber, 1(4), pp. 86-94.

Weissberger, A., 2022. *Telegeograohy: Global internet bandwidth rose by 28% in 2022.* Washington,DC: IEEE Communication Society Technology Blog.

Whitehead, B., Andrews, D., Shah, A. & Maidment, G., 2015. Assessing the environmental impact of data centres part 2: Building environmental assessment methods and life cycle assessment. *Elsevier BV,* Volume 93, pp. 395-405.

Wierman, A., Lie, Z., Lie, I. & Mohsenian-Rad, H., 2014. *Opportunities and Challenges for Data Center Demand Response.* s.l., IEEE Xplore.

Zhao, S. & Zhang, X., 2023. Energy Consumption and Heat Island Effect Mitigation Analysis of Different Roofs Considering Superposition Coupling. *Frontiers in Energy Research.*

Zhu, H. et al., 2023. Future data center energy-conservation and emission-reduction technologies in the context of smart and low-carbon city construction,. *Sustainable Cities and Society,* 89(104322).

Zuo, Y., 2019. Certifying green buildings in China: LEED vs. 3-sta. *Journal of Cleaner Productio,* 208(ISSN 0959-6526), pp. 880-888.

Appendix A: Certified LEED Data Centres

Appendix A contains the table of certified LEED data centres, which includes key information such as the certification total score, certification level, year of certification, and location. This table represents data up to February 2024.

For more details about specific data centres and their individual credit scores, further information can be accessed via the U.S. Green Building Council's database of certified projects at the following link: https://www.usgbc.org/projects

Certified Data Centers	Country	Score	Certification	Date
Apple Data Center GuiAn	China	62	Gold	2021
Beijing ZhongEnYun Big Data Campus Bld.8	China	67	Gold	2023
Building 725	United States	60	Gold	2020
CASSINA DC	Italy	66	Gold	2022
China Electronics Cloud InnovationCenter	China	64	Gold	2022

CMB Financial Innovation Tower	China	55	Silver	2020
Construction of Nxtra Data Ltd. Pune-2	India	56	Silver	2020
CPIC R&D and Backup Data Center	China	50	Silver	2016
Ctrls Datacenters Ltd DC-2	India	86	Platinum	2022
Data Center	China	62	Gold	2021
Data Center 1	China	64	Gold	2020
DATA CENTER ECMWF presso TECNOPOLO di BO	Italy	81	Platinum	2021
Data Center OJSC Sberbank of Russia	Russia	56	Silver	2019
Data Center production workshop 2	China	60	Gold	2023

Data Center SONDA - Etapa 1	Chile	50	Silver	2021
Digital Edge, NARRA1	Philippines	63	Gold	2023
Digital Realty: Hillsboro- OR-1/PDX 11	United States	58	Silver	2021
Equinix DA11	United States	54	Silver	2021
Equinix PE3 Stage 1	Australia	41	Certified	2023
Equinix Singapore Pte Ltd - SG4	Singapore	53	Silver	2022
Etisalat Jabel Ali Data Centre A	United Arab Emirates	56	Silver	2023
Facebook NCG 1-2	United States	69	Gold	2022
Ford Enterprise Data Center 1 - 'EDC1'	United States	60	Gold	2019
Ford Enterprise Data Center 2 - 'EDC2'	United States	61	Gold	2020

GDS Beijing No.13 Data Center	China	66	Gold	2023
GDS Beijing No.7 Data Center BJ7	China	62	Gold	2021
GDS Beijing No.8 Data Center BJ8	China	62	Gold	2021
GDS Changshu No.1 Data Center CS1	China	65	Gold	2022
GDS Changshu No.2 Data Center CS2	China	64	Gold	2021
GDS Chongqing No.1 Data Center CQ1	China	63	Gold	2022
GDS Langfang Data Center LF11	China	65	Gold	2023
GDS Langfang No.3 Data Center LF3	China	61	Gold	2021
GDS Langfang No.4 Data Center	China	60	Gold	2023
GDS Langfang No.5 Data Center	China	62	Gold	2023

GDS Langfang No.8 Data Center LF8	China	62	Gold	2021
GDS Langfang No.9 Data Center LF9	China	60	Gold	2021
GDS Shanghai No.12 Data Center SH12	China	66	Gold	2022
GDS Shanghai No.13 Data Center SH13	China	64	Gold	2021
GDS Shanghai No.14 Data Center SH14	China	68	Gold	2022
GDS Shanghai No.17 Data Center SH17	China	66	Gold	2022
GDS Tianjin No.1 Data Center	China	64	Gold	2023
GLP Changshu Data Center A	China	67	Gold	2023
GLP Changshu Data Center B	China	68	Gold	2023

Grainger Lake Forest Data Center	United States	63	Gold	2014
LAMDA Hellix Athens 2	Greece	68	Gold	2016
Microsoft Data Centre BN 14	United States	62	Gold	2022
Microsoft Data Centre DM4	United States	62	Gold	2022
Microsoft Data Centre DSM 10	United States	65	Gold	2022
Microsoft Data Centre DUB 13	Ireland	60	Gold	2022
Microsoft Data Centre MWH04 North	United States	60	Gold	2023
Microsoft Data Centre SN7	United States	60	Gold	2023
Moncalieri 45 Nord DC1	Italy	68	Gold	2023
MWH 06	United States	62	Gold	2022

Ping An Fin. Mgt. College Info. Center	China	66	Gold	2022
Project Alfa	Singapore	63	Gold	2023
Project Cardinal at 15 Defu Ave 1	Singapore	60	Gold	2021
Project Wildcat - Data Center	Denmark	63	Gold	2021
SANDMAN	Singapore	60	Gold	2022
SG-5	Singapore	52	Silver	2022
SNL CA New Data Center	United States	61	Gold	2022
Suzhou ZhongAnXin Big Data Campus Bld.11	China	66	Gold	2022
Telia Helsinki Data Center	Finland	73	Gold	2018
TI Sparkle Metamorfosis-2	Greece	66	Gold	2021

Turkiye Is Bankasi AS Atlas Veri Merkezi	Turkey	66	Gold	2018
University Park Data Center	United States	42	Certified	2018
WSU New Data Center	United States	52	Silver	2020
Yotta Infrastructure Solutions LLP-NM1	India	66	Gold	2022
Yovole Networks Data Center	China	64	Gold	2017
ZhenRu Communication Bldg, CT-SH Branch	China	77	Gold	2023
ZhongYunXin Shunyi cloud DATA CENTER	China	70	Gold	2020
Cebrosa DC1	Italy	69	Gold	2024
Data Centre DUB 4 + 5	Ireland	60	Gold	2024

Equinix DX3.1	United Arab Emirates	53	Silver	2023
Equinix FR11x	Germany	43	Certified	2023
Equinix ML5 Building 1	Italy	62	Gold	2023
GDS Langfang Data Center LF15	China	64	Gold	2023
Gulf Data Hub Facilities ICAD.	United Arab Emirates	62	Gold	2023
Intel D2 P5/6 HPC Data Center	United States	64	Gold	2024
LD11	United Kingdom	55	Silver	2023
MORO 2.0 MBR Solar Park Data Center	United Arab Emirates	79	Gold	2024
Mulberry	Italy	42	Gold	2024
Rozzano DC4	Italy	80	Platinum	2023

Tianfu Cloud Big Data Industry Park	China	62	Gold	2023
DLR Totowa Building B	United States	68	Gold	2023

Appendix B: Percentage Average Score (PAS) Values

This appendix provides a list of LEED credits relevant to data centres, along with their respective PAS.

Credits/Prerequisite	Average Percentage
Advanced Energy Metering	99%
LEED AP	99%
Construction Indoor Air Quality Management Plan	98%
Reduced Parking Footprint	95%
Outdoor Water Use Reduction	93%
Construction and Demolition Waste Management	93%
Regional priority	90%
Water Metering	89%
Enhanced Refrigerant Management	89%
Site Assessment	88%
Electric Vehicles	87%
Enhanced Indoor Air Quality Strategies	87%

Indoor Water Use Reduction	86%
Sensitive Land Protection	85%
Integrative Process	85%
Heat Island Reduction	82%
Innovation	79%
Enhanced Commissioning	65%
Optimize Energy Performance	62%
Bicycle Facilities	61%
Light Pollution Reduction	55%
Surrounding Density and Diverse Uses	55%
Optimize Process Water Use	52%
Thermal Comfort	50%
Rainwater Management	48%
Access to Quality Transit	47%
Interior Lighting	47%
Building Life-Cycle Impact Reduction	46%
Low-Emitting Materials	44%
Indoor Air Quality Assessment	39%

Open Space	38%
Sourcing of Raw Materials	33%
Environmental Product Declarations	24%
Green Power & Carbon offset	20%
Acoustic Performance	20%
Quality Views	19%
Renewable Energy	17%
Material Ingredients	15%
Protect or Restore Habitat	14%
Daylight	10%
High Priority Site and Equitable Development	8%
Demand Response/Grid Harmonization	2%