Topic: Assessing Environmental Performance of Wind Energy Systems in Commercial Buildings: A Life Cycle Analysis Approach to Reduce Construction Carbon Footprint in the Middle East

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Abstract

The significant construction carbon footprint of commercial buildings in the rapidly developing Middle East presents a critical challenge to regional decarbonization goals. While wind energy systems offer a path to reduce operational emissions, their own "upfront" carbon footprint remains poorly understood from a Life Cycle Analysis (LCA) perspective. This dissertation aims to critically explore the practical challenges and opportunities of using an LCA-based approach to reduce the construction carbon footprint of buildings integrating these systems. Adopting a qualitative methodology, the study draws on semi-structured interviews with six senior industry professionals, architects, engineers, and consultants, practicing in the Gulf region. The data was interpreted using thematic analysis. The findings reveal a systemic cycle of inaction where technical challenges, such as the high embodied carbon of necessary structural reinforcements, are compounded by prohibitive upfront costs and a lack of financial incentives. This is further entrenched by a policy vacuum, with no specific building codes or embodied carbon mandates, and a pervasive professional skills gap exacerbated by a lack of trusted, local case studies. The study concludes that while LCA is an essential informational tool, its ability to drive meaningful carbon reduction is severely constrained. Its effective implementation is contingent upon systemic change, requiring targeted policy interventions, industry-wide upskilling, and the development of a regional evidence base to break the current cycle of risk aversion.

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List of Abbreviations

LCA — Life Cycle Assessment.

LCI — Life Cycle Inventory.

LCIA — Life Cycle Impact Assessment.

CO_2e — Carbon dioxide equivalent.

GHG — Greenhouse Gas(es).

BIM — Building Information Modelling.

HVAC — Heating, Ventilation and Air Conditioning.

CAPEX (CapEx) Capital Expenditure.

OPEX — Operational Expenditure.

LCCA — Life Cycle Cost Analysis.

ISO — International Organization for Standardization (e.g., ISO 14040/14044).

IEA — International Energy Agency.

IPCC — Intergovernmental Panel on Climate Change.

IRENA — International Renewable Energy Agency.

ICE — Inventory of Carbon & Energy.

UAE — United Arab Emirates.

UNEP — United Nations Environment Programme.

GWEC — Global Wind Energy Council.

CHAPTER 1: INTRODUCTION

1.1 Research Background

The escalating global climate crisis, driven by anthropogenic greenhouse gas (GHG) emissions, mandates an urgent and comprehensive transition towards sustainable energy systems and decarbonized economies (IPCC, 2023). Because of agreements such as the Paris Agreement, nations are now more prompted to rethink and reshape their energy sources. It is recognized that when it comes to climate change, commercial buildings are major consumers of energy and are responsible for related emissions once built, and the process of gathering, manufacturing, transporting, and assembling materials for these buildings is recognized but often overlooked, as a significant part of their environmental impact (UNEP, 2022). Innovation and strong assessment tools are needed in construction because present steps toward decarbonization are not fast enough to attain climate goals (IEA, 2023).

The Middle East region, known for its rapid city growth and heavy reliance on fossil fuels, must respond to new opportunities and challenges during this worldwide shift toward renewable energy sources. The per capita energy usage and carbon emission rates in the region are very high compared to the rest of the world (Al-Horr et al., 2016). Much of the increased energy demand in the Middle East results from commercial buildings needing energy-intensive cooling to deal with the dry heat (Radhi, 2009). Many Middle Eastern countries have committed to using green energy and becoming more sustainable in the future (IRENA, 2022) but making these plans a reality and carefully evaluating sustainable solutions in the commercial building area, especially regarding construction emissions, is still underdeveloped. Conventional building methods in the region focus on keeping costs low and finishing projects fast while ignoring environmental benefits in the long run. Therefore, research tailored to every region is needed to find ways to cut carbon emissions from existing commercial buildings.

1.2 Problem Statement

Wind energy is an established technology that is growing more competitive, providing a significant opportunity to cut down on fossil fuel power and reduce carbon emissions (GWEC, 2023). Commercial buildings can use wind energy, building-integrated turbines, or larger installations on-site (Dayan, 2006). Even though wind energy can generate power with very low emissions, a complete look at its environmental effects requires using the Life Cycle Analysis method (Arvesen & Hertwich, 2012). Therefore, the production, transport, setup, upkeep, and disposal of wind energy equipment lead to using both energy and materials, making it important to include their total carbon footprint when deciding on environmental benefits.

A critical, and often underestimated, component of a building's or an energy system's environmental impact is its construction carbon footprint i.e. the GHG emissions released during the manufacturing of materials, their transportation to site, and the construction process itself (Hammond et al., 2011). These "upfront" emissions occur before the building or system begins its operational life. For renewable energy systems, which are deployed to reduce operational carbon, a high construction carbon footprint can significantly offset or delay the realization of net carbon savings (Padey et al., 2012). Therefore, strategies aimed at minimizing this upfront carbon—through sustainable material selection, efficient design, localized sourcing, and innovative construction techniques are paramount. LCA provides the indispensable methodological framework to systematically quantify these potential life cycle impacts, moving beyond simplistic assessments of operational emissions to offer a more accurate understanding of true environmental burdens, including identifying "hotspots" of environmental impact within their value chain, such as the energy-intensive manufacturing of turbine components (ISO 14040, 1997; Wang et al., 2019).

Despite a growing body of literature on the LCA of utility-scale wind farms (e.g., Oebels & Pacca, 2013; Li et al., 2021) and the environmental performance of commercial buildings in general (Kale et al., 2016), a significant research gap exists at the intersection of these domains, particularly within the specific socio-economic and environmental context of the Middle East. There is a paucity of comprehensive LCA studies that specifically assess wind energy systems designed for or integrated into commercial buildings in this region, with an explicit focus on quantifying and reducing the construction-phase carbon footprint. General LCA data derived from studies conducted in other geographical regions may not be directly transferable due to substantial regional variations in electricity grid carbon intensity, manufacturing processes, material supply chains, transportation logistics, construction practices, and climatic conditions (Crawford, 2011). This knowledge deficit hinders the ability of stakeholders in the Middle East to make evidence-based decisions regarding the adoption and optimization of wind energy solutions for the commercial building sector.

Figure 1: Projected construction growth in the Middle East (Research and Markets, 2023)

This thesis deals mainly with how little is known about the total environmental effect related to the carbon produced by wind energy for commercial buildings in the Middle East. While promoted for operational carbon reduction, their sustainability can be compromised if their embodied carbon, from manufacturing, transportation, and installation is excessively high, especially within the region's often carbon-intensive supply chains (Sharma, 2025). Because of this, people investing in eco-friendly technologies could end up lacking positive effects on the environment or perhaps start with greater emissions. To handle this problem, a thorough Life Cycle Analysis must pay close attention to the environmental effects of construction in each area.

1.3. Research Aim and Objectives

1.3.1 Aim

To critically explore the challenges and opportunities for reducing the construction carbon footprint of commercial buildings in the Middle East through the integration of wind energy systems, analysed via a Life Cycle Analysis (LCA) framework.

1.3.2 Objectives

1. To review the current state of Life Cycle Analysis methodologies and their application to wind energy systems and commercial buildings.
2. To identify the key drivers and barriers (technical, economic, and regulatory) to the adoption of building-integrated wind energy systems in the Middle East.
3. To explore the perceptions and experiences of industry professionals regarding the practical implementation of these systems.
4. To propose a framework of recommendations for stakeholders to effectively reduce the construction carbon footprint using this approach.

1.4 Research Questions

To achieve this purpose, the research will be guided by the following key questions:

1. How can a Life Cycle Analysis (LCA) approach inform the reduction of the construction carbon footprint of commercial buildings in the Middle East through the integration of wind energy systems?
2. What are the primary contributors to the construction carbon footprint of building-integrated wind energy systems in the Middle Eastern context?
3. What are the principal challenges faced by architects, engineers, and policymakers when implementing these systems?
4. What are the best practices and mitigation strategies that can be employed during the design and construction phases to minimize the carbon footprint?

1.5 Rationale and Significance of the Study

This research is significant as it addresses a critical knowledge gap concerning the holistic environmental performance of building-related wind energy applications in the Middle East. Academically, it will contribute a methodological framework and region-specific data that can inform future LCA studies in similar contexts. Practically, the findings will provide actionable insights for architects, engineers, urban planners, developers, and policymakers in the Middle East, enabling them to make more informed decisions regarding the selection, design, and implementation of wind energy systems that genuinely minimize environmental impact across their life cycle.

The scope of this study focuses on the assessment of wind energy systems suitable for commercial buildings (e.g., office buildings, retail complexes) in key urban centers of the Middle East, with examples potentially drawn from countries such as the United Arab Emirates and Saudi Arabia, known for their significant construction activity and renewable energy ambitions. The types of wind energy systems considered will include building-augmented and building-integrated solutions, as well as small to medium-scale on-site turbines (Hyams, 2012). The Life Cycle Analysis will prioritize the "cradle-to-gate" (material extraction, manufacturing, and transport to site) and "gate-to-site-installation" (construction) stages to thoroughly address the construction carbon footprint, while also considering indicative operational and end-of-life impacts to provide a broader life cycle perspective. Delimitations include not exhaustively covering every possible wind turbine technology or every country in the Middle East due to practical constraints. While economic aspects are interlinked, the primary focus will remain on environmental performance, specifically the carbon footprint.

1.6 Methodological Overview

To address the research questions, this dissertation adopts a qualitative research methodology, underpinned by an interpretivist philosophy suited for exploring the complex perceptions of individuals. Primary data was gathered through semi-structured interviews with a purposively selected group of industry professionals, including architects and engineers, operating within the Middle East. The rich, qualitative data from these interviews was then systematically examined using thematic analysis. This approach facilitates an in-depth exploration of the practical challenges and opportunities associated with implementing wind energy systems, providing nuanced insights that quantitative methods alone could not capture.

1.7 Dissertation Structure

This dissertation is structured into six chapters to logically present the research. Chapter One introduces research background, problems, aims, and objectives. Chapter Two provides a critical review of the literature on Life Cycle Analysis and wind energy systems, culminating in a conceptual framework. Chapter Three details and justify the qualitative methodology. Chapter Four presents the thematic analysis of the findings from the primary data. In Chapter Five, these findings are critically discussed in relation to the literature to answer the research questions. Finally, Chapter Six concludes the study and provides actionable recommendations for stakeholders and future research. Figure 2 displays the dissertation structure.

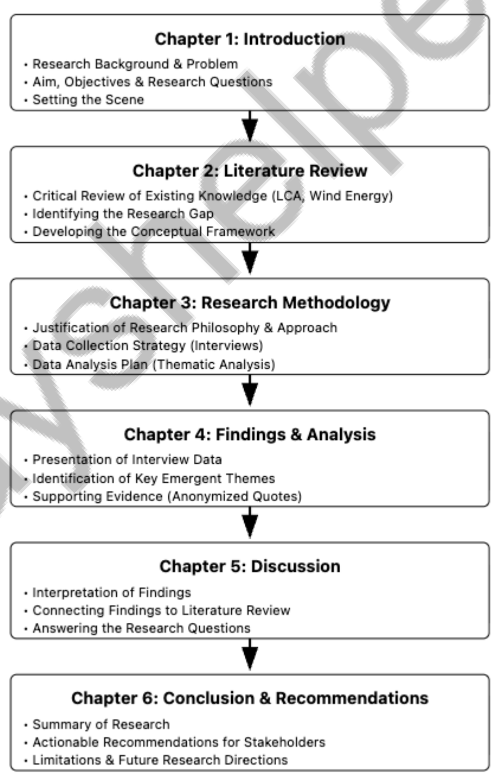

Figure 2: Dissertation Structure

CHAPTER 2: LITERATURE REVIEW

2.1 Chapter Introduction

The objective of this chapter is to establish a comprehensive theoretical foundation for the research. It will achieve this by critically reviewing and synthesising existing academic and industry literature across three core domains: the principles of Life Cycle Analysis (LCA), the application of LCA within the built environment, and the specific context of wind energy systems for commercial buildings. The review begins by defining the standardised frameworks of LCA, establishing its credibility as a tool for environmental impact assessment. It then navigates the complexities of applying this tool to commercial buildings, with a specific focus on the challenges prevalent in the Middle East and the critical debate surrounding embodied versus operational carbon. The chapter proceeds to analyse the current body of knowledge on building-integrated wind energy, critically evaluating existing LCA studies to highlight a significant gap in the literature concerning their construction-phase carbon footprint. By systematically deconstructing these areas, this chapter identifies the key theoretical concepts and defines the precise research gap that this dissertation aims to address. The synthesis of these findings culminates in the development of a conceptual framework, which will provide the theoretical scaffolding for the primary data collection and analysis detailed in subsequent chapters.

It is claimed that the use of fossil fuels for the generation of electricity is the source of 35.29% of all pollutants emissions which are responsible for global warming and climate change (Nassar, Aissa and Alsadi, 2017). One of the most significant sources of renewable energy in the world is wind energy which lowers the reliance on fossil fuels. According to Xu et al., (2018), the use of life cycle evaluation process makes it easy to understand how electric power is generated from wind energy and that helps with understanding the financial and environmental effects of producing electricity through it. A number of studies have been undertaken to prove the feasibility of wind energy for the generation of power. Life cycle assessment (LCA) is a tool which is used by decision makers to compare different technologies and energy systems so as to assess the environmental consequences throughout the life cycle of the project. This tool is relevant so as to determine the best technology to be used. Life cycle of an energy system or a technology is basically the carbon footprint which starts from production, incorporates the transportation, installation, operation, maintenance, and ends with decommissioning and final disposal. The objective of this chapter is therefore to explore the performance of wind energy systems in commercial buildings, and also to explore the life cycle model to see the impact on carbon footprints.

2.2. Life Cycle assessment: A conceptual basis for measurement

LCA is a method that is used to determine the processes initiated due to delivery of or demand for a specific product or service and the impact on it on the environment (Arvesen and Hertwich, 2012). The International Standards Organization (1997) further explains that LCA approach entails systematic mapping of operations and the environmental implications that occur during the life cycle of the product. As a result, the approach enables the provision of a complete picture of the environmental burdens created by a single product.

There are two ways to quantify the life cycle inventories which are in use. One is the conventional LCA methodology that Arvesen and Hertwich (2012) refer to as the process LCA which is a bottom-up approach undertaken to explain the operations in physical terms. This approach allows the user to use the data which is specific to the operations. Hence, the results generated contain high level of accuracy. Oeebels and Pacca (2013) state that while this is a useful approach to ascertain a product's impact but there is a downside to the approach as well. This is in terms of the fact that a cut-off criterion needs to be applied which excludes operations that do not contribute significantly enough. A second approach of measurement is the input-output analysis of the environmental implications. This is a top-down approach where inventories are quantified through the use of monetary data at the level of economic sectors. For this approach there is no need for cut-offs but the limitation of this approach is that it works at a high level of aggregation. Dammeier *et al.,* (2019) explains that there is a hybrid method too where the process LCA is used for modelling the important operations whereas the input-output analysis is used for those operations that are omitted from the former method. Hence, this way the benefits of both approaches can be captured.

The methodological rigor of LCA is governed by the International Organization for Standardization, primarily through the ISO 14040:2006 and ISO 14044:2006 standards. These standards provide a structured, four-phase framework to ensure that assessments are systematic, transparent, and verifiable (ISO, 2006a). The first phase, Goal and Scope Definition, is foundational, as it defines the purpose of the study, the system boundaries, the functional unit (e.g., one square meter of office space over a 60-year lifespan), and the assumptions that will govern the assessment. This phase is critical because an ill-defined scope can lead to misleading or irrelevant conclusions (Finnveden et al., 2009).

The second phase, Life Cycle Inventory (LCI), involves the meticulous collection of data on all environmental inputs (e.g., raw materials, energy, water) and outputs (e.g., emissions to air, water, and soil; waste) for every process within the defined system boundary. The accuracy of the entire LCA is heavily dependent on the quality of the LCI data, which is often sourced from large databases such as Ecoinvent or GaBi (Kalverkamp, Helmers and Pehlken, 2020). The third phase, Life Cycle Impact Assessment (LCIA), translates the inventory data into potential environmental impacts. This involves classifying emissions into impact categories (e.g., global warming potential, acidification potential) and then characterizing them using scientific conversion factors, such as expressing various greenhouse gases in terms of carbon dioxide equivalents (CO2e) (Hauschild et al., 2018).

The final phase, Interpretation, involves evaluating the results from the LCI and LCIA phases in the context of the study's goal and scope. This includes identifying significant environmental hotspots, assessing the sensitivity of the results to key assumptions, and drawing conclusions and recommendations (ISO, 2006b). A crucial aspect of the scope definition phase is the selection of system boundaries, which determines which life cycle stages are included. In the context of the built environment, these are typically defined as "cradle-to-gate," "cradle-to-site," or "cradle-to-grave," each providing a different level of analytical depth (Cabeza et al., 2014). For this study, the focus is primarily on the "upfront" carbon emissions associated with the construction phase, making the "cradle-to-site" boundary particularly relevant as it encompasses material production, manufacturing, and transportation prior to the building's operational life.

Table 1: LCA Phases and their Relevance to Construction Carbon Assessment

LCA Phase (ISO 14044)	Description	Relevance to Construction Carbon Assessment
1. Goal and Scope Definition	Defines the purpose, functional unit, and system boundaries of the assessment.	Determines whether the focus is on the whole building or a specific system (e.g., wind turbine). Sets the boundary (e.g., "cradle-to-site") to isolate construction-phase emissions.
2. Life Cycle Inventory (LCI)	Collects data on all material/energy inputs and environmental outputs for each process.	Requires gathering specific quantities of materials (concrete, steel) and energy used in manufacturing and transport. The accuracy depends heavily on regional LCI databases.
3. Life Cycle Impact Assessment (LCIA)	Translates inventory data into potential environmental impacts (e.g., Global Warming Potential).	Converts the inventory data (e.g., kg of steel) into the final carbon footprint (kg CO_2e), allowing for comparison between different design options.
4. Interpretation	Evaluates the results, identifies environmental "hotspots," and provides recommendations.	Identifies which materials or processes (e.g., turbine manufacturing vs. foundation concrete) contribute most to the carbon footprint, guiding design decisions.

2.3 Life cycle assessment of commercial buildings

The application of Life Cycle Analysis in the built environment has grown significantly as the industry confronts its substantial environmental impact. Globally, buildings are responsible for approximately 39% of energy and process-related carbon emissions, with operational emissions accounting for 28% and embodied carbon from the construction and materials manufacturing phase accounting for 11% (UNEP, 2021). Historically, the focus of sustainable building design was overwhelmingly on reducing operational energy through measures like improved insulation and efficient HVAC systems. However, as buildings become more energy-efficient, and as electricity grids decarbonize, the relative importance of embodied carbon has grown dramatically (Röck et al., 2020). Embodied carbon refers to the GHG emissions produced during the extraction, manufacturing, transportation, and installation of building materials. These "upfront" emissions occur before the building is even occupied, creating a carbon debt that must be "paid back" over the building's life ((Lützkendorf and Balouktsi, 2022).

LCA provides the essential framework for quantifying and managing these impacts. Numerous studies have applied LCA to commercial buildings globally to identify environmental hotspots and compare design alternatives. For instance, studies in Europe and North America have demonstrated that the structural system and building envelope are typically the largest contributors to a commercial building's embodied carbon, often accounting for over 50% of the total (Lützkendorf and Balouktsi, 2022). These analyses enable designers to make informed decisions at the early design stages, where the potential to influence the environmental performance is greatest. For example, selecting timber over concrete for a structural frame, or choosing locally sourced façade materials, can lead to significant reductions in the upfront carbon footprint (Zhao and Haojia, 2015).

Despite its proven benefits, the effective implementation of LCA in the built environment faces several challenges, which are particularly acute in the Middle East. A primary barrier is the scarcity of high-quality, regional Life Cycle Inventory (LCI) databases (Alhazmi et al., 2021). Most established LCI databases, such as Ecoinvent, are based on European or North American manufacturing processes, electricity grid mixes, and transportation logistics. Using this data for a project in, for example, the UAE or Saudi Arabia, can lead to significant inaccuracies. The carbon intensity of electricity, the efficiency of local manufacturing plants, and the distances materials travel are all highly region-specific factors that fundamentally alter the LCA results (Liu, Shafique and Luo, 2023). This data gap forces practitioners to rely on generic data, undermining the credibility of the assessment and hindering its adoption by the local industry.

Furthermore, the unique climatic and construction practices of the Middle East present distinct challenges. The extreme heat necessitates energy-intensive cooling, which has historically placed the focus squarely on operational carbon. This has led to a building stock often characterized by heavy, high-thermal-mass materials like concrete and blockwork, which have a very high embodied carbon content (Radhi, 2009). The conventional construction methods in the region, driven by rapid development cycles, often prioritize speed and cost over environmental performance, further entrenching the use of carbon-intensive materials.

There is extensive research on how the model was convened and how it came useful in context of different industries. For example, Schade (2007) presented a structural overview of theoretical economic models for the analysis of LCC. Kishk et al., (2003) used it in context of the construction sector. Then studies used the approach to evaluate net savings such as Marszal and Heiselberg (2009) exploring the use of renewable energy in attaining net zero energy buildings. Different renewable energy solutions have been integrated as part of the LCC analysis to see the savings. This means that cost of energy consumption is a key component of the annual expenditure in commercial buildings. For example, according to the Melnyk et al., (2021) the cost of energy consumption can be lowered through the use of renewable energy sources. Likewise, wind energy is another renewable energy source used in LCC assessment of commercial buildings and the impact it creates in terms of zero emissions.

This context intensifies the debate on embodied versus operational carbon. In a modern, well-insulated commercial building in a hot climate, the embodied carbon from its construction can be equivalent to many years of its operational carbon emissions (Shadram et al., 2016). Ignoring these upfront emissions provides a distorted picture of the building's true environmental impact. As Middle Eastern nations pursue ambitious sustainability goals, such as those outlined in Saudi

Vision 2030 and the UAE's Net Zero 2050 initiative, the failure to address embodied carbon represents a critical blind spot. Therefore, a tailored LCA approach that considers regional data and construction typologies is not merely an academic exercise but a practical necessity for achieving genuine decarbonization in the region's rapidly expanding built environment.

2.4 Impact of wind energy on the environment

As a mature and increasingly cost-effective renewable energy technology, wind power presents a compelling solution for reducing the operational carbon footprint of commercial buildings. Unlike large-scale, remote wind farms, building-sited wind energy systems generate power at the point of consumption, reducing reliance on the grid and minimizing transmission losses (Dayan, 2006). These systems can be broadly categorized into three types: Building-Integrated Wind Turbines (BIWT), which are architecturally integrated into the building's form (e.g., the Bahrain World Trade Center); Building-Augmented Wind Turbines, where the building's form is used to channel and accelerate wind flow towards the turbines; and On-site installations, which involve freestanding small- to medium-scale turbines located on the property of the commercial building (Mertens, 2006).

The primary environmental benefit of these systems is their near-zero-emission operation. By displacing electricity that would otherwise be generated from fossil fuel-powered grids, they directly reduce a building's operational carbon footprint (Staid & Guikema, 2015). The potential for carbon reduction is significant; Jacobson and Masters (2001) argued that large-scale wind power adoption could meet the requirements of international climate protocols. However, a comprehensive environmental assessment requires looking beyond the operational phase. As Padey et al. (2012) critically observe, wind energy is not entirely "clean" from a life cycle perspective. The manufacturing, transportation, installation, maintenance, and eventual decommissioning of wind turbines all consume energy and resources, resulting in an embodied carbon footprint.

A considerable body of literature has used LCA to quantify the environmental impacts of wind energy, though it suffers from a critical limitation relevant to this study. The vast majority of these LCAs have focused on large, utility-scale onshore and offshore wind farms (Arvesen &

Hertwich, 2012; Bonou et al., 2016). These studies have provided valuable insights, for example, identifying that the manufacturing of the tower and turbine components (blades, nacelle) is the primary contributor to the life cycle emissions (Oebels & Pacca, 2013; Martinez et al., 2009). Studies have quantified the lifetime emission intensity of wind power to be as low as 5.0 to 8.2 g CO_2/kWh, a fraction of that from fossil fuels (Wang & Sun, 2012; Wagner et al., 2011).

Studies on LCA of wind turbines have often been focused on low power capacity production which typically is less than 1 MW. Schleisner (2000) for example performed a study on the first wind turbine LCA for a 500-kW turbine. Similarly, Ardente et al., (2008) performed life cycle analysis of a wind farm that operated 11 turbines having an estimate power output of 660 kW. Khan et al., (2005) performed LCA of a hybrid wind turbine system that comprised of fuel cells and a wind turbine having a power rating of 500 kW. Bonou et al., (2016) was however performed on two onshore and two offshore wind power plants and hence were based on large wind farms. The study found that materials were a source of 70% of the climate change that impacted offshore and onshore. Martinez et al., (2009) performed a study exploring the environmental implications of wind turbines in Spain using the LCA and it was found that the foundation phase contributed the greatest to the environmental implications. Oebels and Pacca (2013) performed a study on 141.5 MW wind farm of Brazil and it was found that 50% of the emissions resulted from the manufacture of tower and only 6% was contributed by the transportation. Moreover, it was found that the intensity of the emissions of carbon dioxide was 7.10 g CO_2/kWh in Brazil. Wagner et al., (2011) was another study which supported same findings. The study carried out LCA on a German offshore wind farm alpha ventus and it was found that 1kWh electricity generated from the wind farm also generated 0.137 kWh primary energy equivalent and 32 g of carbon dioxide equivalent. Al-Behadili and El-Ost (2015) carried out LCA on the Dernah wind farm situated in Libya. It was found that the energy payback period was 0.475 years, having a payback ratio of 42:1. Hence, all of these studies have shown that wind energy produces the lowest carbon emissions per kWh of electricity as compared to fossil fuels.

Raadal et al., (2014) has been another study which corroborates the above results. The study explored the greenhouse gas emissions and the energy performance of an offshore wind power farm. There were 6 different 5MW offshore wind turbines as part of the evaluation. It was found that greenhouse gas emissions varied between 18 and 31.4 g carbon dioxide equivalents per kWh whereas the energy performance was assessed in terms of the energy payback time and energy payback ratio which varied between 1.6 and 2.7 years, and 7.5 and 12.9 respectively. Wang and Sun (2012) formed an innovative approach to determine the carbon emissions per kWh produced throughout the life cycle of a wind farm. The study used 4 wind farms and it was found that existing wind power plants had a lifetime emission intensity of 5.0 to 8.2 g CO2/kWh electricity.

However, these findings are not directly transferable to the context of commercial buildings. First, the scale is vastly different. The materials, manufacturing processes, and installation logistics for a multi-megawatt turbine are not comparable to those for smaller turbines used in building applications. Second, the integration with a building introduces new system boundaries and components that are absent in standalone farms. The structural reinforcements needed to support a turbine, the specialized mounting equipment, and the electrical integration with the building's systems all have their own embodied carbon that must be accounted for (Li et al., 2021). The failure to include these associated facilities and building modifications leads to an underestimation of the true environmental impact.

This points to a clear and significant research gap: there is a scarcity of comprehensive LCA studies that specifically assess the construction-phase carbon footprint of integrating wind energy systems into commercial buildings, particularly within the Middle Eastern context. The existing literature on utility-scale farms provides a methodological starting point, but a dedicated analysis is required to understand the unique material flows, energy inputs, and environmental hotspots associated with building-sited systems. Such an analysis is essential for architects, engineers, and developers to make evidence-based decisions, ensuring that the pursuit of operational carbon reduction does not inadvertently lead to an unacceptably high embodied carbon footprint.

Table 2: Matrix of Wind System Types and Commercial Building Suitability

System Type	Description	Best Suited For	Key LCA Considerations
Building-Integrated	Turbines are part of the architectural design (e.g., between two towers).	New-build, high-rise iconic projects.	High structural embodied carbon (reinforcements), complex installation.
Building-Augmented	Building shape funnels wind to turbines (e.g., roof design).	New-builds or major retrofits with aerodynamic potential.	Embodied carbon specialized architectural forms and mounting systems.
On-Site (Freestanding)	Small turbines are installed on the building's roof or grounds.	Most flexible; suitable for new-builds and retrofits with available space.	Embodied carbon of the turbine itself, foundation, and electrical systems.

2.5 Synthesis and Conceptual Framework

The preceding review of the literature reveals a critical intersection of opportunities and challenges. On one hand, LCA is a robust methodology for assessing and mitigating the embodied carbon of commercial buildings, an issue of growing importance in the Middle East. On the other hand, building-integrated wind energy offers a promising path to reduce operational carbon, but its own embodied carbon footprint remains largely un-quantified in this specific context. The synthesis of the literature, therefore, exposes a clear research gap: a lack of empirically grounded understanding of the practical barriers and drivers for adopting an LCA-based approach to reduce the construction carbon footprint of commercial buildings implementing wind energy systems in the Middle East.

To structure the investigation into this gap, a conceptual framework is proposed. This framework, derived from the key themes identified in literature, organizes the complex, interrelated factors that influence the decision-making process and implementation of these systems. It serves as a theoretical guide for the primary data collection, ensuring that the inquiry is both comprehensive and focused. The framework is built upon four foundational pillars:

1. Technical Feasibility and Challenges: This pillar addresses the engineering and logistical aspects of implementation. The literature suggests that while technically possible, integrating wind turbines into buildings involves significant hurdles. These include structural integration challenges, such as managing vibration and dynamic loads on the building frame, which can add considerable embodied carbon through reinforcements (Poerschke et al., 2011). Furthermore, the efficiency of turbines in turbulent urban wind environments is a major concern, affecting the energy payback and overall environmental business case (Mertens, 2006). This theme also encompasses the sourcing of materials and turbine components, which, in the Middle East, may involve long supply chains with high transportation-related emissions.

2. Economic Viability: This theme explores the financial drivers and barriers. The high upfront capital costs of both the turbines and the necessary structural modifications are a primary deterrent for developers (Noori, 2013). While Life Cycle Cost Analysis (LCCA) can demonstrate long-term savings, the focus in the region's fast-paced construction sector often remains on initial costs (Kale et al., 2016). The viability is further complicated by the lack of targeted financial incentives, such as subsidies or tax credits, for building-sited wind energy, which are often available for larger-scale renewable projects (Timmons, Harris and Roach, 2014).

3. Policy and Regulatory Landscape: This pillar consider the governance structures that enable or hinder adoption. The literature points to a lack of supportive building codes and standards that specifically address the integration of renewable energy systems like wind turbines. Ambiguous regulations regarding grid connection for small-scale producers (net metering) and a lack of streamlined permitting processes can create significant administrative barriers (Hamilton et al., 2018). The absence of government mandates or strong policy signals for reducing embodied carbon further weakens the impetus for developers and designers to adopt LCA methodologies.

4. Stakeholder Awareness and Expertise: This final theme addresses the human factors involved. There is often a significant knowledge gap among key stakeholders, including architects, engineers, and building owners, regarding the real-world performance of building-integrated wind systems and the practical application of LCA (Shadram et al., 2016). A perception of high risk, coupled with a lack of local case studies and established best practices, fosters a reluctance to innovate. This pillar acknowledges that technology and policy alone are insufficient if the professional community lacks the skills, confidence, or motivation to implement them.

This four-pillar framework, as shown in figure 3, provides a holistic lens through which to examine the research problem. It posits that the successful reduction of the construction carbon footprint is not merely a technical calculation but is contingent on the interplay of these technical, economic, policy, and social factors.

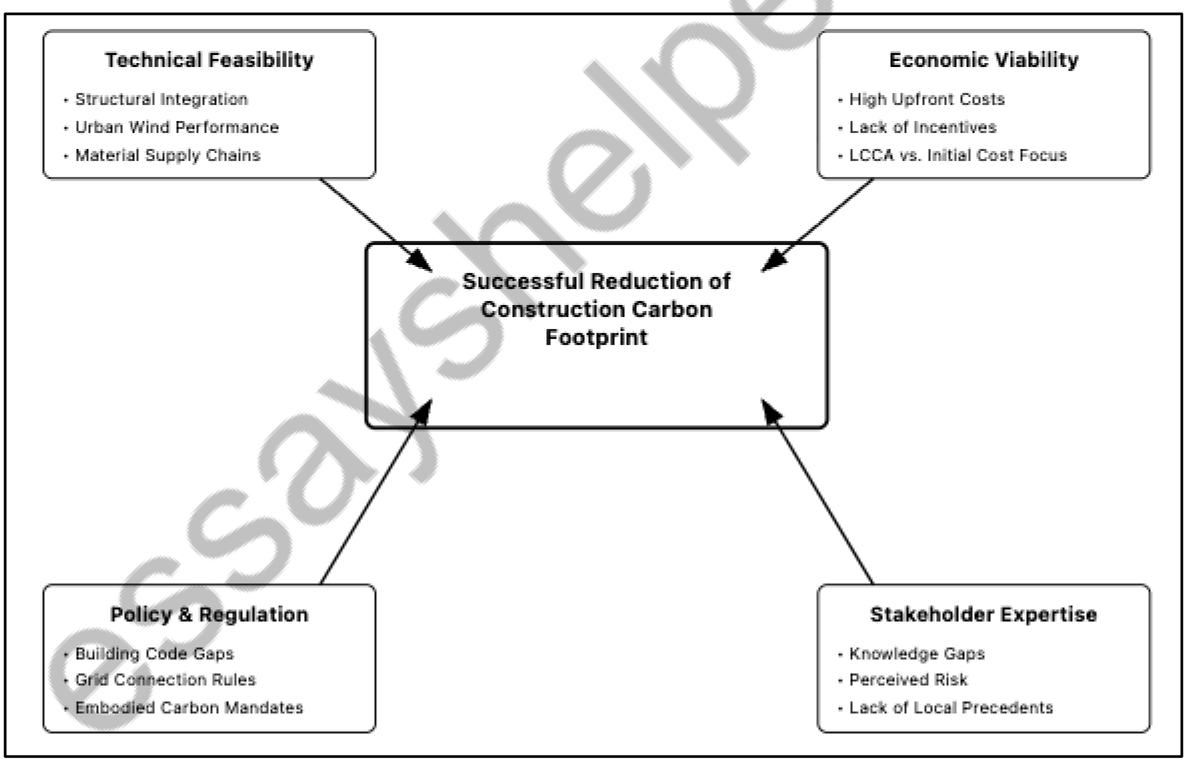

Figure 3: Conceptual Framework for Analyzing LCA Adoption for Wind Energy in Commercial Buildings

2.6 Chapter Summary

This chapter has established the theoretical context for the dissertation. It began by outlining the standardised principles of Life Cycle Analysis, confirming its suitability for environmental assessment. The review then critically examined the application of LCA to the built environment, highlighting the escalating importance of embodied carbon and identifying the specific challenges—notably the lack of regional LCI data—that impede its effective use in the Middle East. Subsequently, the chapter assessed the literature on building-sited wind energy systems, revealing a significant research gap concerning the absence of dedicated LCAs for their construction phase, as existing studies predominantly focus on utility-scale applications. Through a synthesis of these findings, a conceptual framework was developed, structured around four key themes: technical feasibility, economic viability, policy landscape, and stakeholder awareness. This framework not only defines the boundaries of the research problem but also provides a robust theoretical foundation to guide the empirical investigation that will be detailed in the following chapter on methodology.

Chapter 3: RESEARCH METHODOLOGY

3.1 Introduction

This chapter provides a detailed and robust justification for the research methodology employed to answer the central research question: How can a Life Cycle Analysis (LCA) approach inform the reduction of the construction carbon footprint of commercial buildings in the Middle East through the integration of wind energy systems? Acting as the architectural plan for the empirical investigation, this chapter systematically outlines the philosophical underpinnings, the research approach, and the specific strategies and methods used to collect and analyse data. It details the rationale behind the selection of a qualitative methodology, the use of semi-structured interviews for data collection, and thematic analysis as the interpretive lens. Figure 4 displays the overall research design. Furthermore, this chapter addresses the critical ethical considerations that governed the research process and acknowledges the inherent limitations of the chosen design.

Figure 4: Overall research design

3.2 Research Philosophy

Any research investigation is founded upon a research philosophy, which encompasses the researcher's assumptions about the nature of reality (ontology) and the nature of knowledge (epistemology) (Saunders, Lewis, & Thornhill, 2019). These assumptions fundamentally shape the research questions, the methods used to answer them, and the interpretation of the findings. The primary research philosophies in social and management sciences are positivism, interpretivism, and pragmatism. Positivism posits that reality is objective and singular, and knowledge can be obtained through empirical observation and testing, often using quantitative methods to establish causal relationships. In contrast, interpretivism contends that reality is subjective and socially constructed, meaning that knowledge is gained by exploring the meanings and interpretations that individuals assign to their experiences (Creswell & Poth, 2018). Pragmatism offers a third way, focusing on the practical consequences of research and advocating for the use of mixed methods that best address the research problem.

Table 3. Ontological and epistemological assumptions and their design implications.

Philosophy	Ontology	Epistemology	Aims	Data	Why accepted/rejected
Positivism	Single, objective reality.	Objective, empirical knowledge.	Test hypotheses.	Quantitative (surveys, experiments).	Rejected: Unsuitable for subjective stakeholder views.
Interpretivism (selected)	Subjective, constructed reality.	Subjective, contextual knowledge.	Explore meanings.	Qualitative (interviews, case studies).	Accepted: Fits study's focus on stakeholder perceptions.
Pragmatism	Objective and subjective reality.	Practical, context-based knowledge.	Solve problems.	Mixed methods (surveys, interviews).	Rejected: Too complex for qualitative focus.

For this dissertation, an interpretivist philosophy was adopted. This choice is directly informed by the research aim, which seeks to explore the complex challenges, opportunities, and perceptions surrounding the implementation of a niche sustainable technology within a specific socio-economic context. The research questions are not concerned with measuring statistical correlations but with understanding the "why" and "how" of decision-making processes among industry professionals. A positivist approach, such as a large-scale survey, would be inadequate for capturing the nuanced reasons behind technical choices, the subtle influence of policy gaps, or the deeply held perceptions of risk and viability among architects and engineers in the Middle East. Interpretivism, however, provides a framework for engaging in these subjective realities. It acknowledges that the "barriers" to adopting LCA and wind energy systems are not objective facts waiting to be discovered, but are constructed through the lived experiences, professional cultures, and shared understandings of the stakeholders involved (Gephart, 2004). Therefore, by adopting an interpretivist stance, this research is positioned to generate a rich, contextualised understanding of the phenomenon that is grounded in the perspectives of those who navigate it directly.

3.3 Research Approach

The research philosophy informs the research approach, which dictates the logical path from theory to data. The two primary approaches are deductive and inductive. A deductive approach is a top-down logic where a researcher starts with a pre-existing theory or hypothesis and collects data to test its validity. It is commonly associated with positivism and quantitative research (Bryman, 2016). Conversely, an inductive approach is a bottom-up logic where a researcher begins with specific observations and data, from which broader patterns, themes, and eventually theories emerge. This approach is intrinsically linked to interpretivism and qualitative research, as it allows insights to be generated directly from the data rather than being constrained by a pre-existing theoretical framework.

This study employs a primarily inductive approach. The central goal is to allow an understanding of the challenges and opportunities to emerge from the rich narratives of the research participants. While the conceptual framework developed in Chapter Two provides a guiding structure for the inquiry, it is intended as a lens rather than a rigid hypothesis to be tested. The inductive approach ensures that the research remains open to discovering unforeseen themes and unexpected connections that may not be present in the existing global literature but are critically important within the specific context of the Middle East. This flexibility is essential for an exploratory study, as it allows the final conclusions to be authentically grounded in the empirical data collected (Thomas, 2006). This method ensures that the perspectives of the professionals are not forced to fit a preconceived model but are instead used to build a more nuanced and contextually relevant understanding of the research problem.

3.4 Research Strategy and Methodological Choice

The research strategy is the specific plan of action for conducting the research, informed by the chosen philosophy and approach. Given the interpretivist philosophy and inductive logic, a qualitative methodology was selected as the most appropriate choice. Qualitative research is designed to explore phenomena in-depth and within their natural settings, focusing on understanding the meanings individuals and groups ascribe to a social or human problem (Denzin & Lincoln, 2018). This methodology is uniquely suited to answering the "why" and "how" questions that are central to this dissertation. It allows for a detailed exploration of the complex interplay between technical, economic, and policy factors that would be lost in the aggregated data of a quantitative survey.

The specific strategy employed is an exploratory, multi-case study approach. In this context, each participating professional and their unique set of experiences represents a "case." This strategy does not aim to produce statistically generalizable results but rather to generate deep, contextualised insights that can be compared and contrasted across different professional roles (e.g., architect, engineer, energy consultant) to build a holistic picture of the issue (Yin, 2018). By examining the phenomenon through the distinct lenses of multiple expert practitioners, the research can uncover shared patterns of experience as well as points of divergence, leading to a richer and more comprehensive understanding. This approach is particularly valuable for investigating contemporary, real-world problems where the boundaries between the phenomenon and its context are not clearly evident, as is the case with technology adoption in the construction industry.

3.5 Data Collection

The primary data for this study was collected through semi-structured interviews. This method was chosen over structured interviews, which can be overly rigid and prevent exploration, and unstructured interviews, which can lack focus and consistency. The semi-structured format provides the optimal balance, using a pre-prepared interview guide to ensure that key topics derived from the conceptual framework are covered with each participant, while also allowing the flexibility to ask probing follow-up questions and explore emergent themes as they arise during the conversation (Kvale & Brinkmann, 2015). This adaptability is crucial for gathering rich, detailed narratives.

The sampling strategy employed was purposive sampling. This non-probability technique involves the deliberate selection of participants based on their specific knowledge, experience, and professional roles relevant to the research topic (Patton, 2015). Participants were identified based on their explicit expertise in architecture, engineering, or sustainability consulting, with demonstrated experience working on commercial building projects in the Middle East. The target sample size was set at six to eight participants, with the final number determined by the principle of data saturation. Saturation is the point at which new interviews cease to generate new themes or insights, indicating that a sufficient depth of data has been collected (Guest, Bunce, & Johnson, 2006).

The recruitment process was initiated through professional networks and platforms like LinkedIn. Potential participants were sent the Participant Information Sheet (see Appendix B), which detailed the research purpose, procedures, and ethical considerations. Upon their agreement to participate, they were asked to sign the Consent Form (see Appendix C). All interviews were conducted online via Microsoft Teams, were audio-recorded with explicit consent, and typically lasted between 40 and 60 minutes. An interview guide, based directly on the conceptual framework themes from Chapter Two, was used to steer the conversation (see Appendix D).

3.6 Data Analysis

The method chosen for analysing the qualitative data from the interview transcripts was thematic analysis. Thematic analysis is a foundational method for identifying, analysing, and reporting patterns (themes) within qualitative data. It provides a flexible yet rigorous approach to organizing and describing the dataset in rich detail (Braun & Clarke, 2006). This study followed the widely recognized six-phase framework developed by Braun and Clarke (2006) to ensure a systematic and transparent analysis process.

The first phase, familiarisation with the data, involved transcribing the audio recordings verbatim and repeatedly reading through the transcripts to gain an intimate understanding of the content. In the second phase, generating initial codes, the researcher systematically worked through the entire dataset, identifying and labelling features of the data that appeared interesting or relevant to the research questions. The third phase, searching for themes, involved collating the various codes into potential overarching themes and gathering all the relevant coded data extracts under these themes. During the fourth phase, reviewing themes, the initial set of themes was refined. Some themes were combined, others were split, and some were discarded, ensuring that the themes were coherent and accurately represented the dataset. The fifth phase, defining and naming themes, involved writing a detailed analysis for each theme to articulate its essence and its relationship to the overall research narrative. The final phase, producing the report, involved weaving together the analytic narrative and vivid data extracts to tell a coherent and persuasive story about the data, which is presented in Chapter Four.

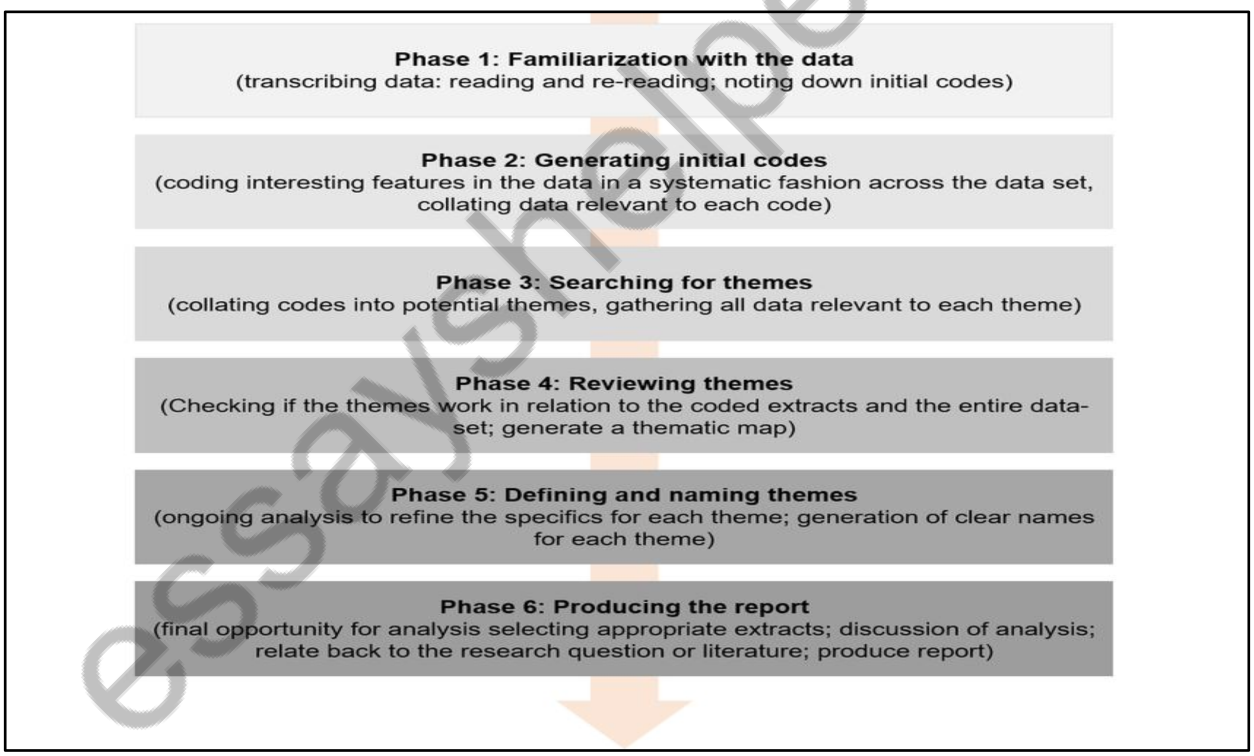

Figure 5: Six-phase thematic analysis workflow applied to interview transcripts (V Vien Lee et al., 2024)

3.7 Ethical Considerations and Limitations

This research was conducted in strict adherence to the ethical guidelines of the University of the West of England (UWE), as documented in the approved Ethics Checklist (see Appendix A). The foundational principle was the protection of participants. Informed consent was secured in writing from all participants prior to their interviews, ensuring they fully understood the purpose of the research and their role within it. Anonymity and confidentiality were paramount. All participants were assigned a code (e.g., P1, P2) to ensure their identities were not revealed in the dissertation, and any identifying information mentioned in the transcripts was removed. Data was stored securely on a password-protected computer, and audio recordings were permanently deleted after transcription, in line with the data management plan. Participants were explicitly informed of their right to withdraw from the study at any point without penalty.

The primary limitation of this qualitative study is that its findings are not statistically generalisable to the entire construction industry in the Middle East. However, the aim of interpretivist research is not generalisability but transferability, the extent to which the findings can be relevant to other, similar contexts (Lincoln & Guba, 1985). By providing a thick description of the context and the participants' experiences, this study offers insights that are likely to resonate with and be transferable to other professionals and projects in the region. Another potential limitation is researcher bias; however, this was mitigated through reflexivity, a process of continuous self-examination of the researcher's own assumptions and their potential influence on the data interpretation.

3.8 Chapter Summary

This chapter has provided a comprehensive and justified account of the research methodology. It established the selection of an interpretivist philosophy and a primarily inductive approach as the most appropriate framework for this exploratory study. The research strategy was defined as a qualitative, multi-case study, with data collected through semi-structured interviews with purposely selected industry experts. The rigorous six-phase thematic analysis process for interpreting the data was detailed. The chapter has also affirmed the study’s commitment to the highest ethical standards and transparently acknowledged its limitations. This robust methodological foundation ensures the credibility and trustworthiness of the research findings, which are presented and analysed in the subsequent chapter.

CHAPTER 4: FINDINGS AND ANALYSIS

4.1 Introduction

The purpose of this chapter is to present and systematically analyse the primary data collected to address the dissertation's central aim: to explore the challenges and opportunities for reducing the construction carbon footprint of commercial buildings in the Middle East through an LCA-based approach to wind energy systems. The findings presented herein are derived from a thematic analysis of in-depth, semi-structured interviews conducted with six industry professionals representing a cross-section of the disciplines involved in the design and delivery of commercial buildings in the region.

The analysis of the transcribed interviews revealed a complex and multifaceted landscape of opinions and experiences. Four principal themes emerged as the dominant organizing frameworks for the data: (1) Technical and Implementation Challenges, which encompasses the practical engineering and logistical hurdles, (2) The Economic and Financial Landscape, which details the powerful influence of cost, investment, and value perception, (3) Policy, Regulation, and Standards, which explores the overarching governance structures that shape project feasibility, and (4) Professional Knowledge and Perceptions, which addresses the critical human factors of skills, awareness, and industry culture.

This chapter will present each theme and its constituent sub-themes in sequence. The analysis is supported by direct, anonymized quotations from the participants to ensure that the findings remain authentically grounded in their lived experiences. A variety of tables and figures are used to summarize, visualize, and underscore the key findings, providing a clear and comprehensive account of the empirical evidence upon which the discussion in Chapter Five will be based.

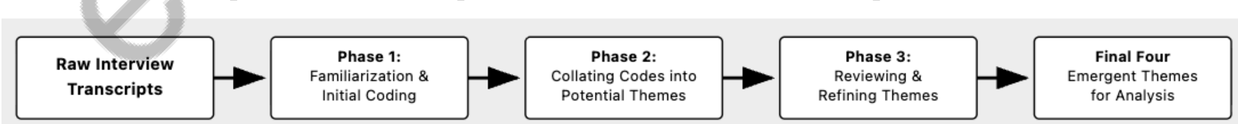

Figure 6: Thematic Analysis Process Flow

4.2 Participant Demographics

The study involved six participants who were selected purposively to ensure a diverse range of expertise and perspectives from across the project lifecycle. The sample included senior professionals with extensive experience in the UAE, KSA, and Qatar, providing a robust and relevant cross-section of the industry within the target geographical region. The distribution of professional roles, as shown in Figure 7, provided a balanced view between design ideation (Architects), technical execution (Engineers), and holistic oversight (Consultant, Project Manager).

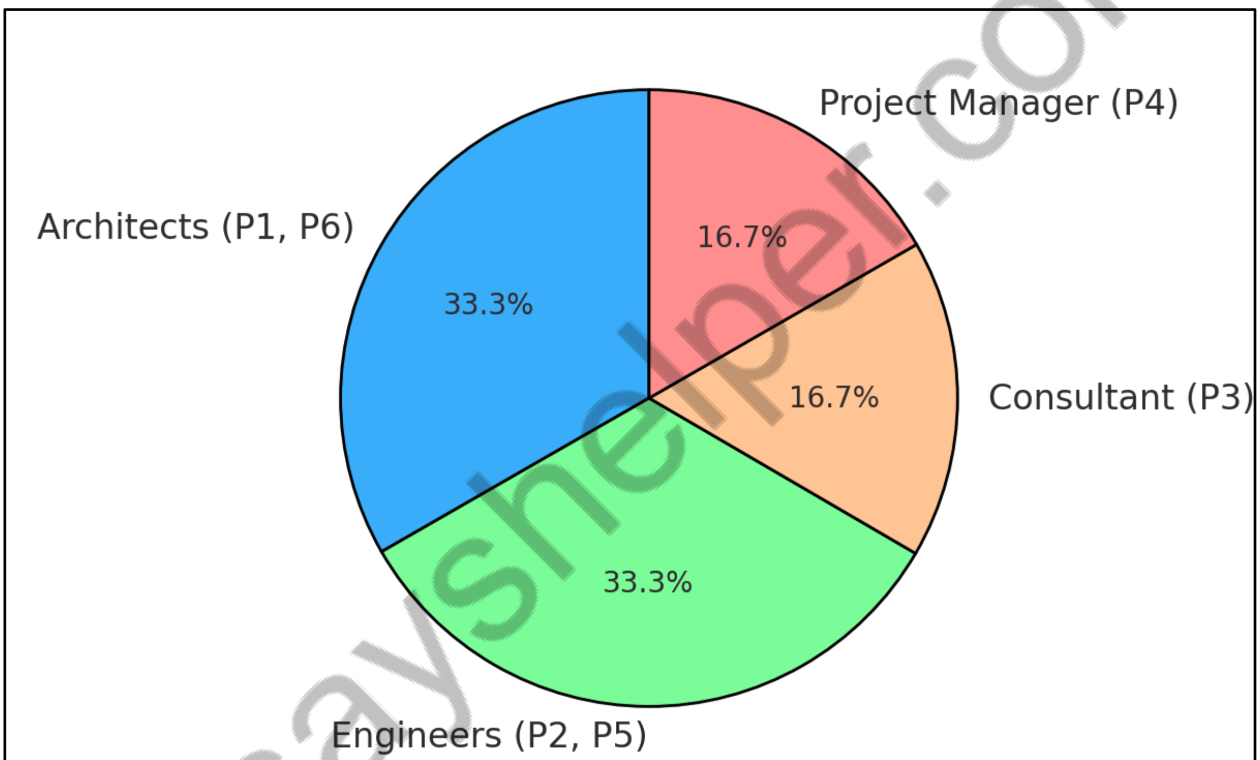

Figure 7: Distribution of Participant Professional Roles

Table 4 provides a more detailed, anonymized summary of the participant profiles to contextualize the findings that follow.

Table 4: Anonymized Summary of Participant Profiles

Code	Professional Role	Years of Experience	Primary Region of Practice	Area of Expertise
P1	Senior Architect	18	UAE (Dubai)	Iconic High-Rise Commercial Design
P2	Structural Engineer	22	KSA (Riyadh)	Complex Structures & Material Science
P3	Sustainability Consultant	12	Qatar (Doha)	Whole Life Carbon & LCA Modelling
P4	Senior Project Manager	20	UAE (Abu Dhabi)	Project Delivery & Risk Management
P5	MEP Engineer	15	KSA (Jeddah)	Building Services & Energy Systems
P6	Architect	6	UAE (Dubai)	BIM & Digital Design Integration

4.3 Theme 1: Technical & Implementation Challenges

The most frequently and vividly discussed set of barriers related to the fundamental technical and practical challenges of integrating wind energy systems into commercial buildings. Participants across all disciplines highlighted that, despite the conceptual appeal, the path from design to operation is fraught with complex engineering problems and logistical hurdles that are often underestimated. These challenges were consistently framed not as insurmountable, but as factors that add significant complexity, risk, and, crucially, embodied carbon to a project.

4.3.1 Structural and Material Integrity

The most immediate concern, raised unanimously by the architects and engineers, was the issue of structural integrity. The conversation moved quickly beyond the simple static weight of the turbines to the more complex dynamic loads they impose on a building's frame. As P2 (Structural Engineer) stated with emphasis:

"It's not the static weight that's the issue but the constant vibration and fatigue from the turbine's operation, especially in gusty conditions. That introduces a whole new level of complexity and risk to the structural design that clients simply do not appreciate."

This sentiment was echoed by P1 (Senior Architect), who noted the cascading impact on material selection and, therefore, on the construction carbon footprint.

"To manage those dynamics, you inevitably need more structure. That means more concrete, more steel, more embodied carbon right from the start."

Participants explained that these structural reinforcements are a significant source of "hidden" embodied carbon, which is rarely accounted for in preliminary feasibility studies that focus only on the turbine itself. This challenge is particularly acute in retrofitting projects, where the existing structure was never designed to accommodate such dynamic forces. Table 5 summarises the key technical barriers as identified by the interviewees, highlighting the consensus around structural issues.

Table 5: Summary of Key Technical Barriers Identified by Participants

Barrier Category	**Specific Challenge**	**Primary Impact**	**Mentioned By**
Structural	Dynamic Loads & Vibration	Increased material use (embodied carbon)	P1, P2, P4

Performance	Urban Wind Turbulence	Unreliable energy output, poor ROI	P3, P5, P6
Logistical	Component Supply Chain	Delays, high transport emissions	P4, P1
Integration	MEP & Grid Connection	System complexity, safety concerns	P5, P2
Data	Lack of BIM-LCA Interoperability	Manual data entry, inaccurate models	P6, P3

4.3.2 Performance and Efficiency in Urban Environments

Beyond the structural issues, a strong sub-theme emerged regarding the actual energy performance of turbines in dense urban settings. Participants expressed considerable scepticism about the viability of many systems due to the unpredictable nature of wind in cities. The turbulent and chaotic wind patterns created by surrounding tall buildings, known as the "urban canyon effect," were cited as a major performance inhibitor. P5 (MEP Engineer) explained this practically:

"The wind tunnel models look great in a clean, laminar flow. But on-site, with turbulence from adjacent towers, the output is never what's promised. The blades are constantly stopped and the power generation is sub-optimal"

This unreliability directly impacts the carbon payback calculation. P3 (Sustainability Consultant), whose role involves conducting these analyses, described the difficulty in creating a credible model that clients can trust.

"My biggest challenge is the energy yield prediction. The software for this is not as mature as it is for solar … I can't accurately model the operational carbon savings to offset the high embodied carbon."

This finding suggests that a key technical barrier is the significant gap between the theoretical potential of wind turbines and their proven, real-world performance in the complex aerodynamic environments of Middle Eastern cities. Figure 8 visualizes the qualitative assessment of these technical barriers based on participant input, showing that performance issues, while frequently mentioned, were seen as having a slightly lower immediate impact than the core structural challenges.

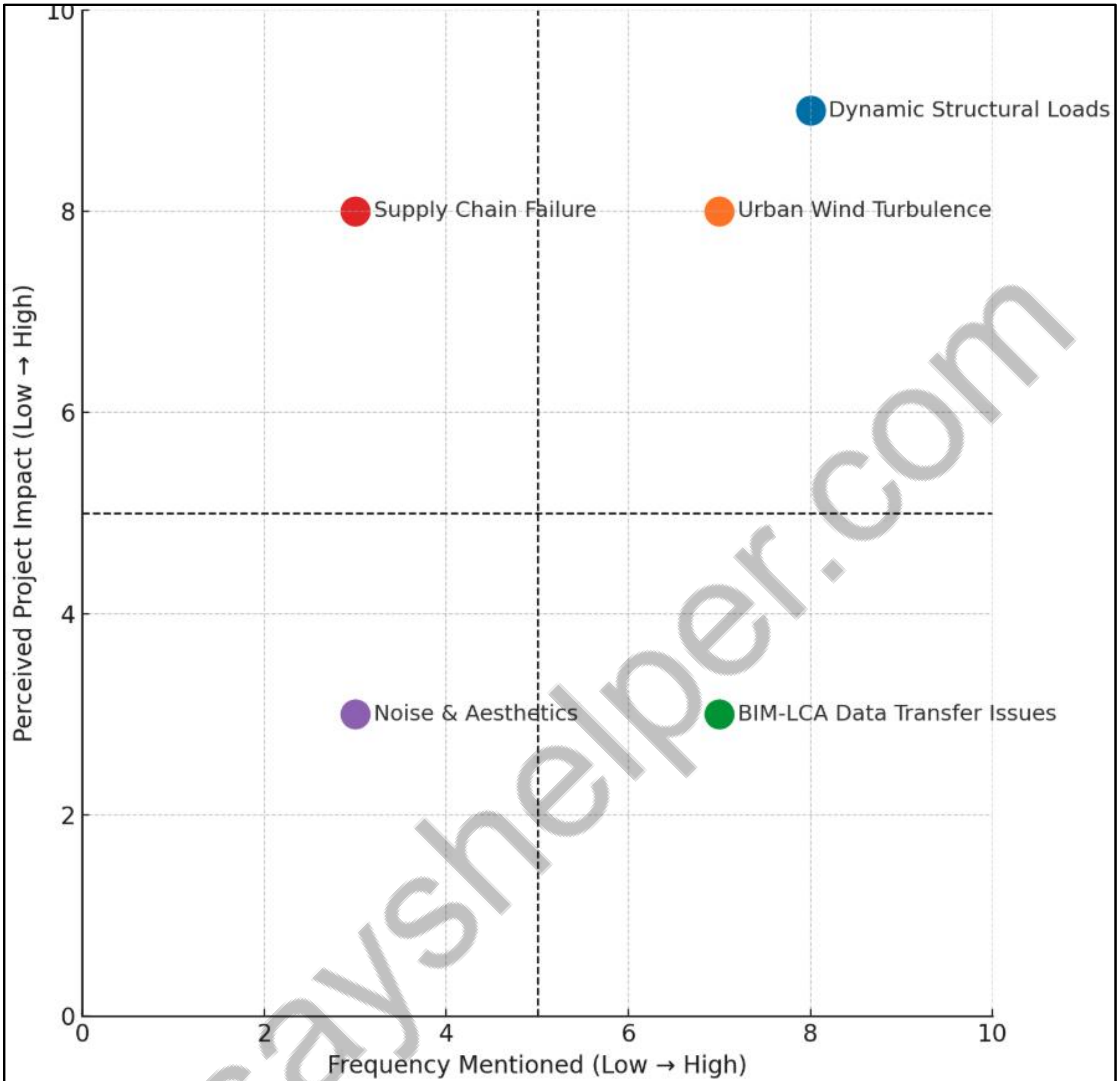

Figure 8: Technical Barrier Impact vs. Frequency Matrix

4.3.3 Supply Chain, Data, and Integration Deficiencies

A final set of technical challenges related to the broader ecosystem of supply chains and digital tools. P4 (Project Manager) highlighted the logistical issues:

"These aren't off-the-shelf items. Sourcing specialized turbines and components often means a complex global supply chain, adding cost, time, and emissions which must be part of the LCA."

This point connects directly to the accuracy of the LCA. The further the components travel, the higher their "cradle-to-site" embodied carbon, a factor often overlooked. Furthermore, on the digital front, a significant frustration was the lack of seamless integration between design and analysis software. P6 (Architect), who works extensively with BIM, articulated this problem clearly:

"The theory of integrated design is great, but the practice simply is not. We have to manually export schedules and material quantities from our BIM model to the LCA software. We have to repeat it every time the design changes."

P3 (Sustainability Consultant) confirmed this, referring to the process illustrated in Figure 9. He added,

"That broken data workflow is a major barrier. It makes performing iterative analysis during the early design stages almost impossible for most teams."

This lack of digital interoperability was seen as a fundamental obstacle preventing LCA from becoming a fluid, integrated part of the design process.

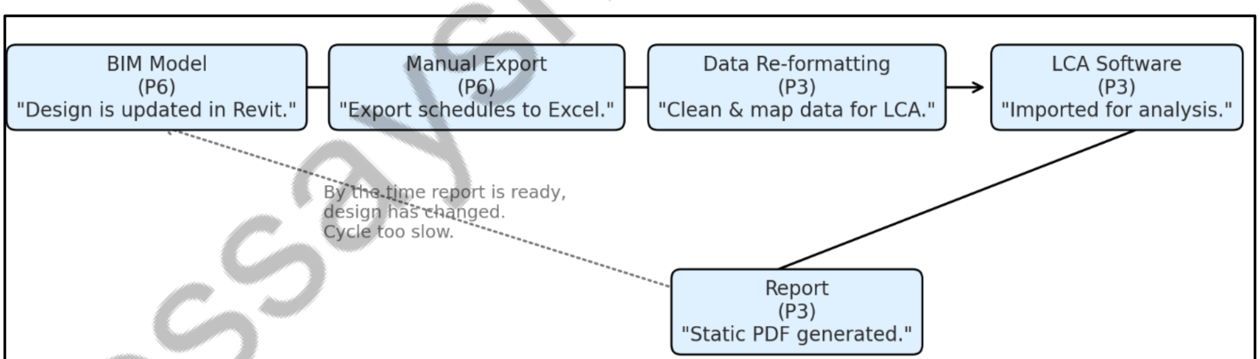

Figure 9: The Disconnected Digital Workflow as Described by Participants

4.4 Theme 2: The Economic and Financial Landscape

Flowing directly from the technical challenges, the economic and financial landscape was identified as an equally powerful, if not greater, determinant of project feasibility. Participants consistently described a decision-making environment heavily weighted towards short-term financial metrics, which places innovative but costly sustainable technologies at a distinct disadvantage. The discussion was dominated by the tension between upfront capital expenditure and long-term life cycle value.

4.4.1 The Dominance of Upfront Capital Cost

The most significant barrier identified by every participant was the high initial capital investment. P4 (Project Manager), who represents the client and developer perspective, was unequivocal:

"At the end of the day, the decision comes down to the budget. We operate in a CAPEX-sensitive environment. If it adds 10% to the initial construction cost, it's almost always a non-starter for the client, regardless of the long-term green credentials."

This perspective was shared by P1 (Senior Architect), who often has to present these options. "We can propose the most elegant sustainable solution, but the first question is always 'How much will it cost?' The conversation rarely moves past that initial number." The findings, summarized in Table 6, indicate that the industry's conventional financial models are structured around minimizing capital expenditure (CAPEX), with less emphasis placed on operational expenditure (OPEX) or whole-life value.

Table 6: Participant Ranking of Economic Barriers (1 = Most Critical)

Rank	Economic Barrier	Participant Consensus	Key Rationale from Interviews
1	High Upfront Capital Cost (CAPEX)	Unanimous agreement	"It's the first filter for every decision." (P4)
2	Perceived Technology & Market Risk	Strong agreement	"Investors are wary of unproven tech in this market." (P2)

3	Lack of Targeted Financial Incentives	Strong agreement	"The government supports solar, but wind is left on its own." (P1)
4	"Split Incentive" Problem	Mentioned by most	"The developer pays, but the future tenant saves. It doesn't add up for the investor." (P4)

4.4.2 The Intangibility of Life Cycle Value

While participants like P3 (Sustainability Consultant) are experts in demonstrating long-term value through Life Cycle Cost Analysis (LCCA), they reported immense difficulty in making this case compelling to developers.

"We present the LCCA but for many investors in this region, a projected saving in ten years is less real and far less important than a hard cost on a spreadsheet today."

This highlights a core tension, visualized in Figure 10, between the financial priorities of different project stakeholders. The "split incentive" problem, where the initial investor does not reap the long-term operational savings, was identified by P4 (Project Manager) as a fundamental market failure:

"Many developers haven't held the asset for 30 years. Their model is to build, lease, and sell. The long-term operational savings benefit the future owner, not them."

Without a mechanism to monetize or transfer this long-term value, there is little financial motivation for the initial investor to bear the high upfront cost of the technology.

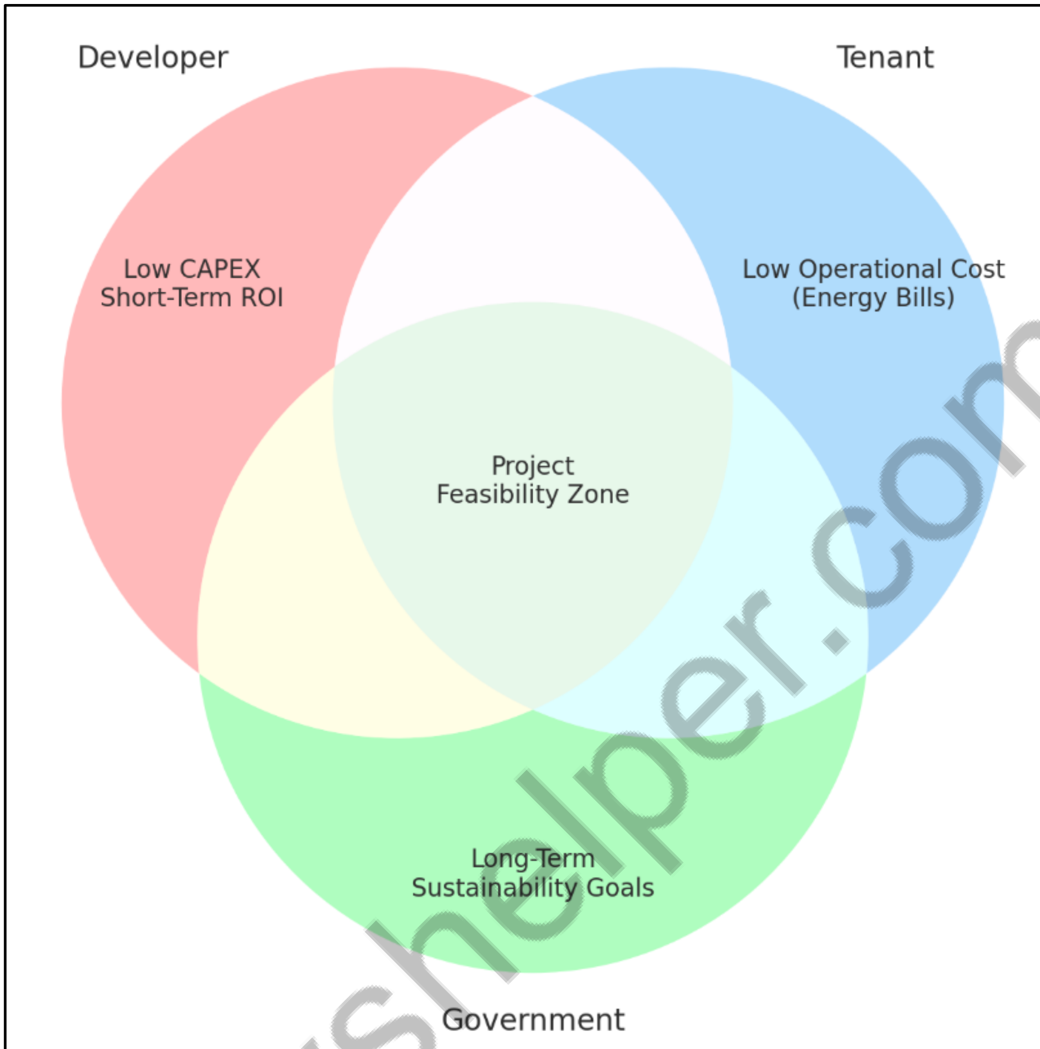

Figure 10: Conflicting Stakeholder Financial Drivers

4.4.3 Perceived Risk and the Absence of Financial Incentives

Compounding the cost issue is the perception of risk. Because building-integrated wind is not mainstream technology in the region, it is viewed as a risky investment. P2 (Structural Engineer) noted,

"There's a risk premium. Insurers, financiers... they all get nervous about an unproven system. That adds indirect costs and headaches to the project that are hard to quantify but very real."

This perception is exacerbated by a lack of strong governmental financial incentives to de-risk the investment. Participants drew a sharp contrast with the solar sector, which has benefited from clear subsidy programs. P1 (Senior Architect) lamented:

"There's no real financial push from the government for this specific tech. If there were attractive feed-in tariffs or significant tax breaks, the conversation with clients would be entirely different. It would change the entire equation."

The absence of this supportive financial architecture, as illustrated in Figure 11, leaves the technology competing on purely commercial terms, where its high CAPEX and perceived risk make it an unattractive proposition for most commercial developers in the current market.

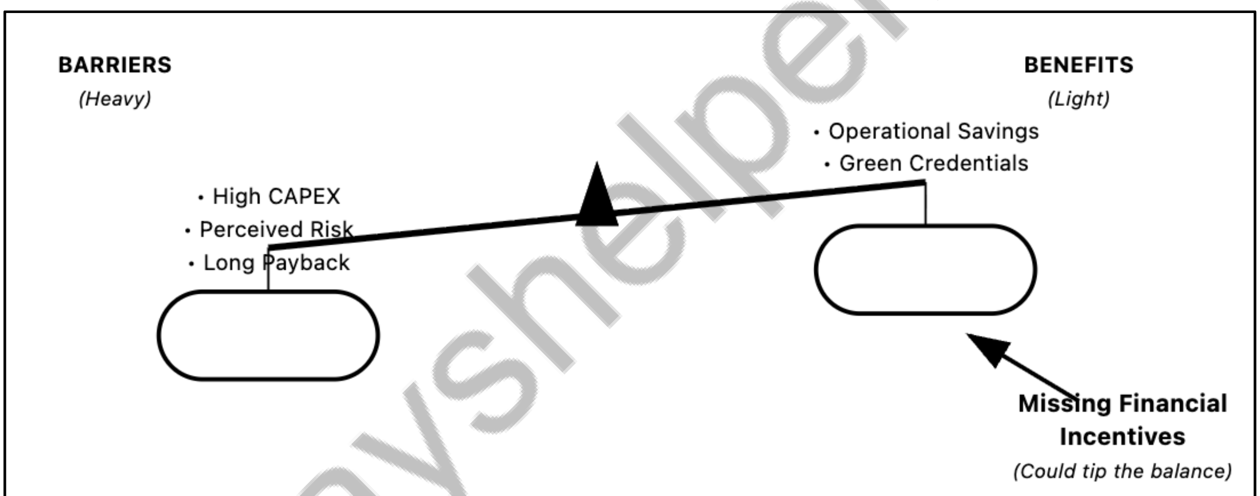

Figure 11: The Tipping Point of Investment Decision

4.5 Theme 3: Policy, Regulation, and Standards

The third major theme to emerge from the interviews was the critical role, and frequent absence, of a supportive policy and regulatory framework. Participants described a landscape characterized by regulatory gaps, ambiguous processes, and a general lack of governmental direction specifically for building-sited wind energy and embodied carbon. This "policy vacuum" was seen as a significant barrier that stifles innovation and creates uncertainty for project teams.

4.5.1 A Vacuum of Specific Standards and Building Codes

A consistent point of frustration, particularly for the engineers, was the lack of specific standards to guide the design and installation of wind turbines on buildings. P2 (Structural Engineer) articulated the problem vividly:

"I have clear, prescriptive codes for seismic design, for fire safety, for literally every other major component. For wind turbine integration? Nothing. We are forced to extrapolate from standards meant for ground-based structures, which is a grey area legally and technically."

Figure 12 shows the frequency chart of regulatory barriers called by participants.

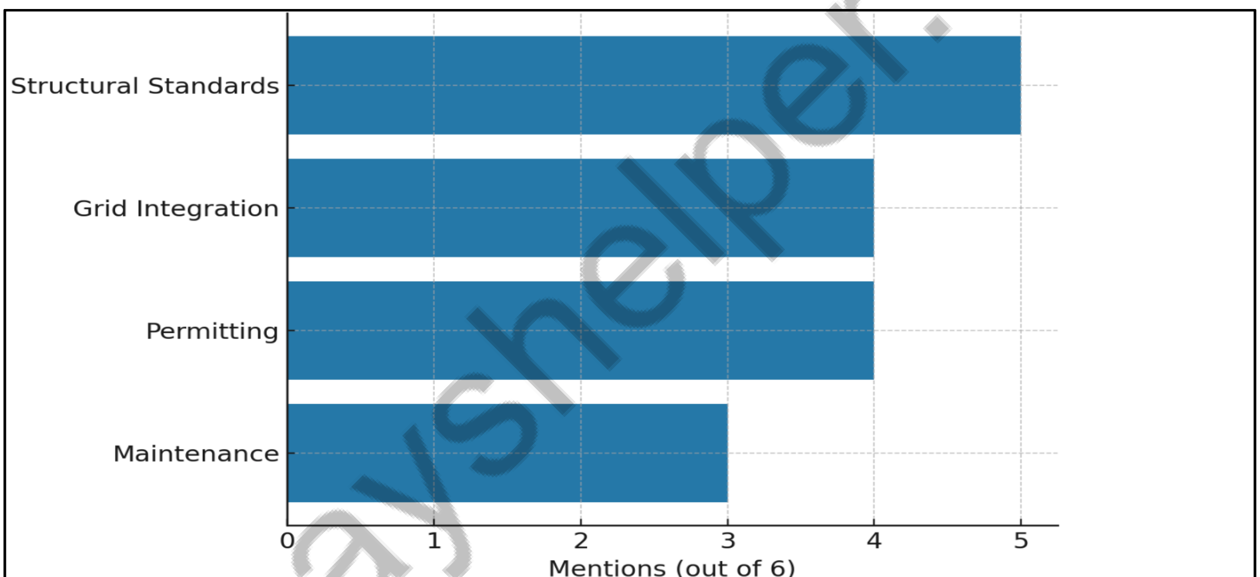

Figure 12: Frequency of Regulatory Barriers Cited by Participants

This absence of clear technical guidance creates significant liability and risk for the design team, as summarized in Table 7. P5 (MEP Engineer) added that this extends to maintenance and safety protocols.

"Who certifies the installation? What are the mandatory inspection schedules? Without a clear standard, it's a bit of a wild west. Everyone is guessing, and that's a dangerous place to be."

Table 7: Analysis of the Regulatory Gap for Wind Turbine Integration

Regulatory Area	Participant Observation	Consequence
Structural Design	"No dedicated codes for dynamic loads on building facades." (P2)	Increased design risk, over-engineering (higher embodied carbon).
Electrical Safety	"Grid connection rules are unclear and vary by utility." (P5)	Uncertainty in design, project delays.
Permitting	"There's no defined approval path; it's a bureaucratic maze." (P4)	Delays and increased administrative costs.
Maintenance	"No standard for long-term inspection and safety." (P5)	Operational risk, potential for system failure.

4.5.2 Ambiguity in Grid Integration and Permitting

The process of connecting a building's energy system to the municipal grid was described as opaque and inconsistent. This uncertainty makes it difficult to build a reliable financial model. The administrative hurdles of permitting were also highlighted as a significant deterrent, a process P4 (Project Manager) described as a "bureaucratic maze," which is visualized in Figure 13.

"The authorities don't have a specific checklist for this. It often gets bounced between departments. Each one asks for different information, and none of them are really sure who has the final say. These delays kill a project's momentum."

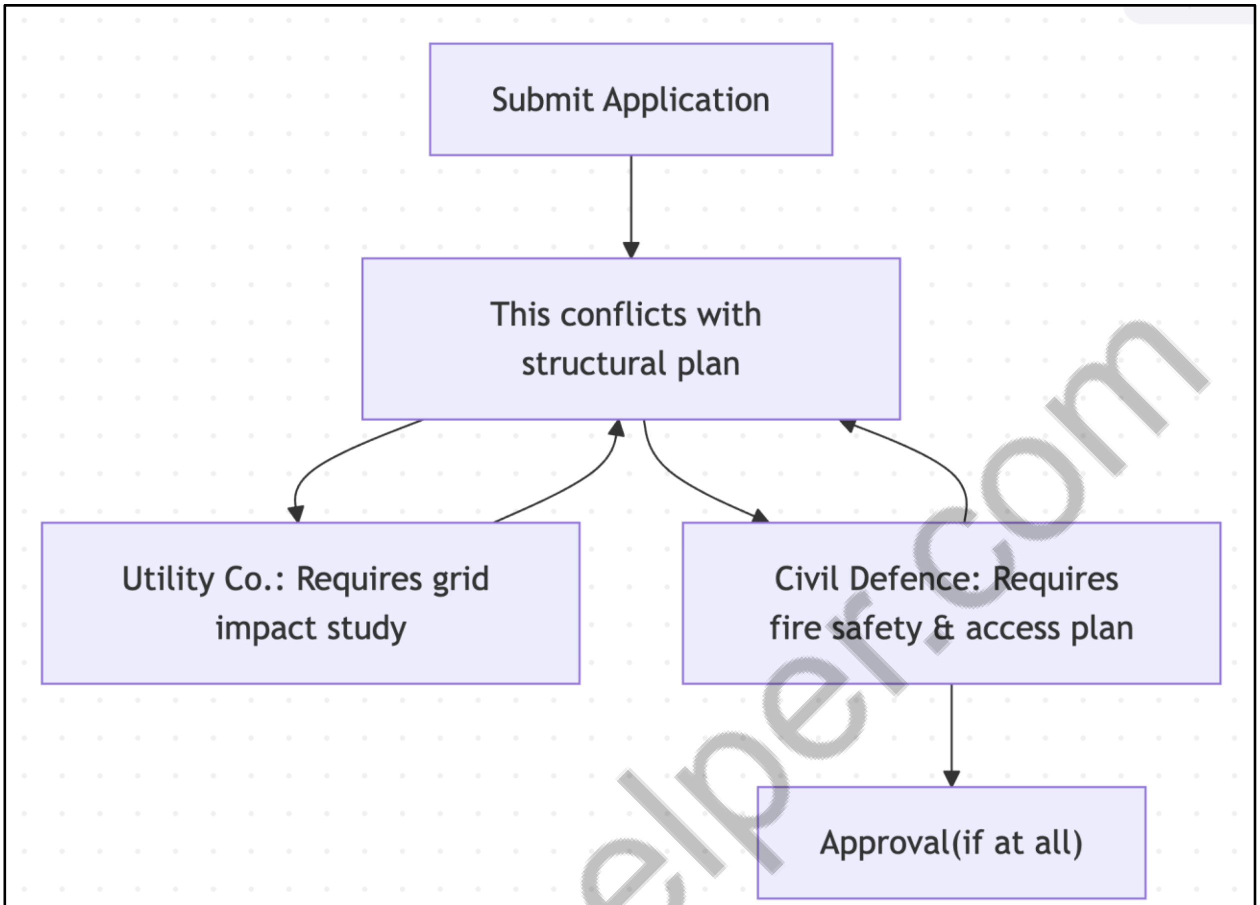

Figure 13: The Permitting "Bureaucratic Maze" as Described by P4

4.5.3 Missing "Push" for Embodied Carbon

Perhaps the most fundamental policy issue identified was the lack of any meaningful regulation targeting embodied carbon. Participants noted that while there is growing governmental rhetoric around sustainability, the actual regulations remain focused almost exclusively on operational energy efficiency. P3 (Sustainability Consultant) was passionate on this point:

"Governments are talking about Net Zero, but their policies and building codes don't reflect the urgency of upfront emissions. There is no mandate to conduct a Whole Life Carbon assessment on major projects, so it remains a 'nice to have' rather than a 'must have'."

Without this regulatory "push," the adoption of LCA remains voluntary and is often one of the first things to be value-engineered out of a project. P6 (Architect) added, *"If the municipality required an embodied carbon calculation for building permit approval, every single firm would learn how to do it overnight. The industry responds to regulation."*

The consensus among participants was that until embodied carbon is integrated into national building regulations, its consideration will remain a niche practice. Figure 14 displays the word cloud of Policy and Regulatory Terms.

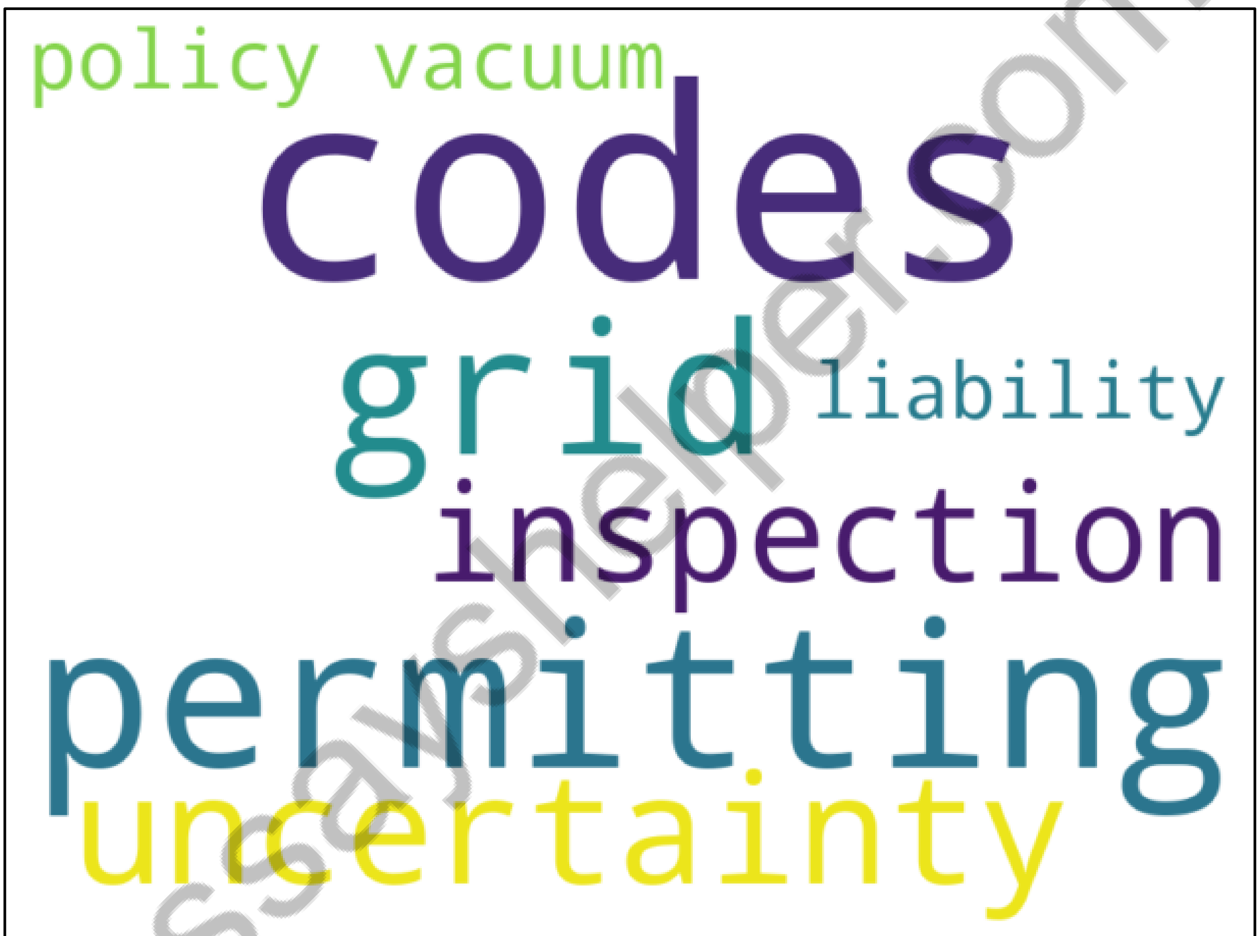

Figure 14: Word Cloud of Policy and Regulatory Terms

4.6 Theme 4: Professional Knowledge and Perceptions

The final theme delves into the human and cultural dimensions of technological adoption. Beyond the technical, economic, and policy barriers, participants described a professional ecosystem where skills gaps, entrenched perceptions, and a lack of local precedent combine to create a powerful inertia against change.

4.6.1 The Pervasive Skills Gap

A recurring point was the lack of widespread, practical expertise in both building-sited wind technology and the application of LCA. P3 (Sustainability Consultant) observed:

"There are very few architects or engineers here who are truly comfortable with LCA. They see it as a specialist task, not as a core design skill, and they don't know how to use the outputs to make better design decisions."

This skills gap, summarized in Table 8, has a direct impact on the design process. P1 (Senior Architect) admitted his own team's limitations, "We are not structural dynamicists or aerodynamicists. We rely heavily on external consultants for this, which adds another layer of coordination and cost and slows everything down." This reliance on a small pool of external specialists makes the process cumbersome and expensive, preventing the kind of fluid, iterative design processes.

Table 8: Summary of Identified Knowledge and Skills Gaps

Discipline	Identified Gap	Consequence
Architecture	Lack of deep knowledge in building aerodynamics and structural dynamics.	Over-reliance on consultants; designs may not be optimized for wind performance.
Structural Engineering	Limited experience with dynamic/fatigue analysis for this specific application.	Conservative, high-mass designs (more embodied carbon); perceived liability.
MEP Engineering	Unfamiliarity with non-standard grid integration and turbine control systems.	Delays in design; conservative performance estimates.

All Disciplines	Low proficiency in practical application of LCA software and interpretation of results.	Inaccurate or incomplete carbon assessments; missed optimization opportunities.

Figure 15 displays the frequency with which knowledge and skills gaps were mentioned by participants across different disciplines, as derived from interview data.

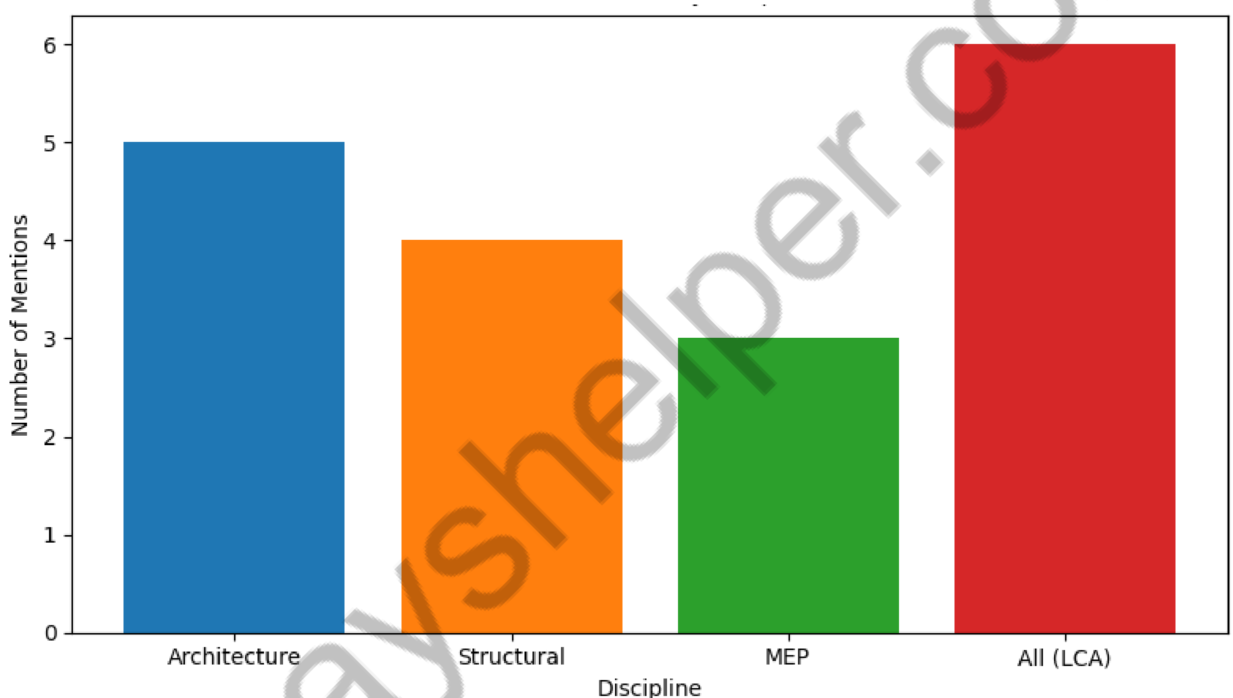

Figure 15: Perceived Knowledge Gaps by Discipline (Participant Mentions)

4.6.2 The Spectrum of Perception: Innovation vs. "Green-Washing"

The perception of building-integrated wind energy among clients and even some professionals is highly varied. On one hand, it is seen as a powerful symbol of innovation. P1 (Senior Architect) noted,

"For the right client, it's an iconic statement. It's a visible commitment to sustainability that can become a key part of the building's brand and marketing narrative."

However, this is countered by deep-seated scepticism, with many viewing the technology as inefficient and more for show than for genuine impact—a phenomenon often described as "green-washing." P4 (Project Manager) captured this cynicism:

> *"Honestly? Most developers see it as a gimmick. They've heard stories about turbines on other buildings that don't even spin. They'd rather spend the money on a fancier lobby than on something they don't believe will actually work or provide a return."*

This negative perception, fuelled by the performance issues discussed in Theme 1, makes it incredibly difficult for design teams to advocate for technology. Figure 16 displays the sentiment spectrum of six participants regarding the adoption of building-integrated wind turbines (BIWTs), as expressed in coded interview responses.

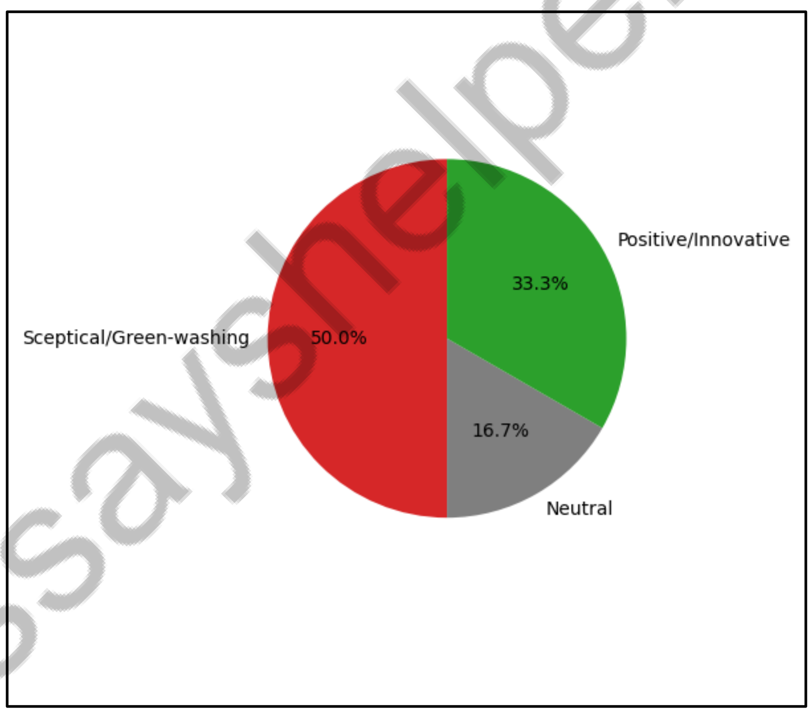

Figure 16: Sentiment Spectrum on BIWT Adoption

4.6.3 The Need for Localized Case Studies and Data

Finally, every participant emphasized the critical need for successful, well-documented local case studies. P2 (Structural Engineer) stated forcefully:

"Don't show me a case study from Germany or Canada. Show me one that has been operating successfully in the Gulf for ten years. The climate, the dust, the humidity, the specific wind patterns, it's all different here. Without local proof, it's all theory."

The absence of this local proof-of-concept creates the "pioneer problem". No one wants to be the first to invest in a risky project, so no local case studies are generated to de-risk it for future investors. P6 (Architect) summarized the sentiment of the group:

"We need pioneers. We need a few high-profile projects to succeed and publish their data openly, both the costs and the actual performance. That's the only way to break the cycle."

Figure 17 displays a word cloud of key terms used by participants when discussing their professional perceptions of Building-Integrated Wind Turbines (BIWTs)

Figure 17: Word Cloud of Perception Terms

4.7 Chapter Summary

This chapter has presented empirical findings from interviews with six industry professionals, organized into four primary themes. The analysis revealed that the adoption of an LCA-based approach for wind energy systems in the Middle East is hindered by a powerful confluence of interconnected barriers. Technical challenges, particularly concerning structural dynamics and unreliable urban wind performance, increase embodied carbon and undermine the business case. This is compounded by an economic landscape dominated by high upfront costs and a financial culture that prioritizes short-term CAPEX over long-term value. These issues are further entrenched by a policy and regulatory vacuum, with a lack of specific standards and no governmental mandates for embodied carbon assessment. Finally, these structural barriers are underpinned by a deep-rooted knowledge and perception gap within the professional community. Table 9 provides a final synthesis of these findings, setting the stage for a critical discussion in the next chapter.

Table 9: Synthesis of Key Findings Across All Themes

Theme	Core Finding from Participant Data	Key Implication for Construction Carbon
Technical & Implementation	Dynamic structural loads and unpredictable urban wind are the primary engineering hurdles.	The "solutions" (e.g., more steel) directly increase upfront embodied carbon, while poor performance negates operational carbon savings.
Economic & Financial	The dominance of CAPEX-focused decision-making makes the high initial cost of technology a near-universal veto point.	Life Cycle Analysis, which demonstrates long-term value, is rendered ineffective in a market geared towards short-term ROI.

Policy & Regulation	There is a critical absence of specific technical standards for installation and no regulatory requirement to measure or mitigate embodied carbon.	Without a regulatory "push," embodied carbon remains an externality, and its assessment remains a voluntary, low-priority task.
Knowledge & Perception	A pervasive skills gap in LCA and a lack of local, trusted case studies foster a culture of risk aversion and scepticism.	The professional ecosystem lacks the capacity and confidence to champion and effectively implement these complex sustainable solutions.

CHAPTER 5: DISCUSSION

5.1 Introduction

The purpose of this chapter is to move beyond the presentation of data to its critical interpretation. It synthesizes the empirical findings detailed in Chapter Four with the theoretical foundations established in the literature review of Chapter Two. This discussion chapter serves as the analytical core of the dissertation, aiming to answer the research questions by comparing and contrasting the lived experiences of industry professionals in the Middle East with existing academic knowledge, thereby generating new insights into the research problem.

5.2 Answering the Research Questions

This section is structured around the dissertation's sub-questions, providing a focused analysis that integrates the primary data with established literature to build a comprehensive answer to each query.

5.2.1 What are the primary contributors to the construction carbon footprint of building-integrated wind energy systems in the Middle Eastern context?

The findings from this research both confirm and significantly expand upon the existing literature regarding the carbon contributors of wind energy systems. The literature on utility-scale wind farms consistently identifies the manufacturing of the turbine components, specifically the tower, nacelle, and blades, as the primary environmental "hotspot" (Oebels & Pacca, 2013; Martinez et al., 2009). While participants did not dispute the significance of the turbine's own embodied carbon, their insights revealed that for building-integrated systems, this is only part of the story. The most emphatic finding, articulated by P2 (Structural Engineer), was that the need for significant structural reinforcement to manage dynamic loads introduces a major source of embodied carbon that is located not in the turbine, but in the building itself. This finding directly supports the arguments of Hosseini et al. (2025) that the "upfront" carbon associated with the building structure is a critical but often overlooked component of a project's total environmental impact.

Furthermore, the data adds a crucial, region-specific nuance concerning supply chain logistics. While the literature acknowledges transportation emissions (Arvesen & Hertwich, 2012), the participants, particularly P4 (Project Manager), framed it as a major contributor due to the lack of local manufacturing for specialized turbine components in the Middle East. This reliance on complex global supply chains means that the "cradle-to-site" emissions, as defined by Cabeza et al. (2014), are likely to be significantly higher than for projects in Europe or North America where manufacturing is more localized. This suggests that applying generic, European-centric LCI data, a concern raised by Alhazmi et al. (2021), would lead to a substantial underestimation of the construction carbon footprint for projects in the Gulf region. Therefore, the primary contributors are not just the turbine itself, but a combination of the turbine, the additional building structure it necessitates, and the extensive transportation required for its delivery.

5.2.2 What are the principal challenges faced by architects, engineers, and policymakers when implementing these systems?

The research findings reveal that the challenges to implementation are not a simple list of discrete problems but a complex, interconnected system of self-reinforcing barriers, which aligns with the socio-technical perspective on technology adoption. The study's four emergent themes map closely onto this complexity.

The technical challenges identified by participants, such as managing structural vibrations and the unpredictable nature of urban wind, confirm the engineering concerns outlined in the literature (Mertens, 2006). However, the findings provide a deeper understanding of how these technical issues create ripple effects. For example, the poor reliability of energy yield prediction, as highlighted by P3 (Sustainability Consultant), directly undermines the credibility of the economic case, transforming a technical problem into a potent financial barrier.

This leads to the second major challenge: the economic landscape. The participants' unanimous emphasis on the dominance of upfront capital cost (CAPEX) confirms the observations of Kale et al. (2016) regarding the financial models prevalent in the construction industry. However, the findings add a critical layer of detail by identifying the "split incentive" problem, articulated by P4 (Project Manager), as a fundamental market failure in the region's build-to-sell development model. This challenges the simplistic notion that merely demonstrating long-term savings through LCCA is sufficient to persuade investors. The data suggests that without a mechanism to bridge this split incentive, LCCA remains a largely academic exercise in the eyes of developers.

Thirdly, the findings on the policy and regulatory landscape paint a picture of a "policy vacuum." The lack of specific building codes, a point vehemently made by P2 (Structural Engineer), creates a high-risk environment of legal and technical uncertainty for designers. This empirical finding gives practical weight to the broader literature that calls for stronger governance and standards to drive sustainable construction (Temitope Omotayo et al., 2024). Most importantly, the observation by P3 and P6 that there is no regulatory "push" for embodied carbon assessment is critical. It suggests that even if the technical and economic issues of wind energy were solved, the motivation to formally assess its construction carbon footprint via LCA would remain low.

Finally, the study reveals that these structural barriers are cemented by a pervasive knowledge gap, confirming the work of Shadram et al. (2016) on the importance of stakeholder expertise. The clear distinction made by participants between their high confidence in conventional design and their low proficiency in LCA and building aerodynamics shows that this is a niche skill set. The call from all participants for local, trusted case studies highlights a critical "pioneer problem." This suggests that the principal challenge is not just a lack of technology or policy, but a lack of tangible, local proof that can overcome a deeply entrenched culture of risk aversion.

5.2.3 What are the best practices and mitigation strategies that can be employed during the design and construction phases to minimize the carbon footprint?

While the interviews focused predominantly on barriers, the participants' detailed descriptions of these problems implicitly pointed towards a set of mitigation strategies and best practices. The most powerful strategy, inferred from the frustrations of P3 and P6 regarding disconnected digital workflows, is the adoption of a truly integrated design process. This involves bringing LCA specialists and structural dynamicists into the project at the very earliest stages, rather than as downstream consultants. This approach would allow for rapid, iterative analysis where the embodied carbon impact of design decisions can be assessed in near real-time, transforming LCA from a reporting tool into a proactive design tool.

A second key strategy is to prioritize passive design and system optimization before technology addition. P1 (Senior Architect) hinted at this when discussing the importance of building form. An effective strategy would be to use computational fluid dynamics (CFD) modelling early in the design phase to shape the building itself to optimize wind flow, a practice central to building-augmented designs (Mertens, 2006). This "fabric-first" approach ensures that any added technology is placed in an environment where it can perform optimally, thereby improving its carbon payback period.

Thirdly, to mitigate the high embodied carbon from both structural reinforcements and long-distance transport, the best practice would be to specify materials with a focus on low-carbon alternatives and localized supply chains. This would require designers to actively seek Environmental Product Declarations (EPDs) for materials and to challenge conventional specifications. For example, exploring the use of lower-carbon concrete mixes or sourcing steel from local recyclers, as advocated by Hossain et al. (2020), could significantly reduce the embodied carbon of the necessary structural upgrades. This, however, is contingent on the availability of regional data, which, as the findings show, remains a significant challenge.

5.3 Implications of the Findings

The findings of this research carry significant implications for theory, practice, and policy within the context of sustainable construction in the Middle East.

5.3.1 Theoretical Implications

From a theoretical perspective, this study contributes to literature by providing a crucial, empirically grounded critique of the direct application of utility-scale wind energy LCAs to the built environment. It demonstrates that the system boundaries for building-integrated systems are fundamentally different and more complex, requiring the inclusion of significant building-related impacts. More importantly, the research provides a nuanced, socio-technical framework for understanding technology adoption in the Gulf's construction sector. It highlights that a purely technocratic or economic analysis is insufficient. The interplay between policy, professional culture, and perceived risk, as revealed in the findings, suggests that future research in this area must adopt a more holistic, system-thinking approach. The study validates the importance of context, showing that global sustainability models must be adapted to account for regional market structures, regulatory environments, and professional capacities.

5.3.2 Practical and Policy Implications

For practitioners, the implications are a clear call for upskilling and a shift in process. Architects and engineers must move towards a more integrated design model and develop core competencies in whole-life carbon assessment to remain relevant in a decarbonizing world. For policymakers, the findings represent an urgent agenda for action. The study strongly suggests that without regulatory intervention, the market will not voluntarily address embodied carbon. The key policy implications are the need to: (1) develop clear technical standards and building codes for renewable energy integration, (2) create meaningful financial incentives to de-risk investment for developers, and (3) most critically, begin the process of mandating whole-life carbon reporting for major projects to create a level playing field and drive industry-wide change.

5.4 Revisiting the Conceptual Framework

The conceptual framework developed in Chapter Two, with its four pillars of technical, economic, policy, and knowledge factors, proved to be a robust and effective tool for structuring the research. The empirical findings from Chapter Four strongly validated the relevance of all four pillars, with each theme corresponding directly to one of the framework's components.

However, the findings also allow for a significant refinement of the initial framework. While the original model presented the four pillars as separate factors influencing the central problem, the interview data revealed the powerful interdependencies and feedback loops between them. For example, a lack of policy (Pillar 3) directly exacerbates the perceived economic risk (Pillar 2). This high risk stifles the creation of local case studies, thus deepening the knowledge and skills gap (Pillar 4), which in turn reinforces the technical uncertainty and reluctance to innovate (Pillar 1). This creates a self-perpetuating cycle of inaction. The revised conceptual framework, presented in Figure 18, visualizes these dynamic interconnections, offering a more sophisticated model that reflects the systemic nature of the challenges.

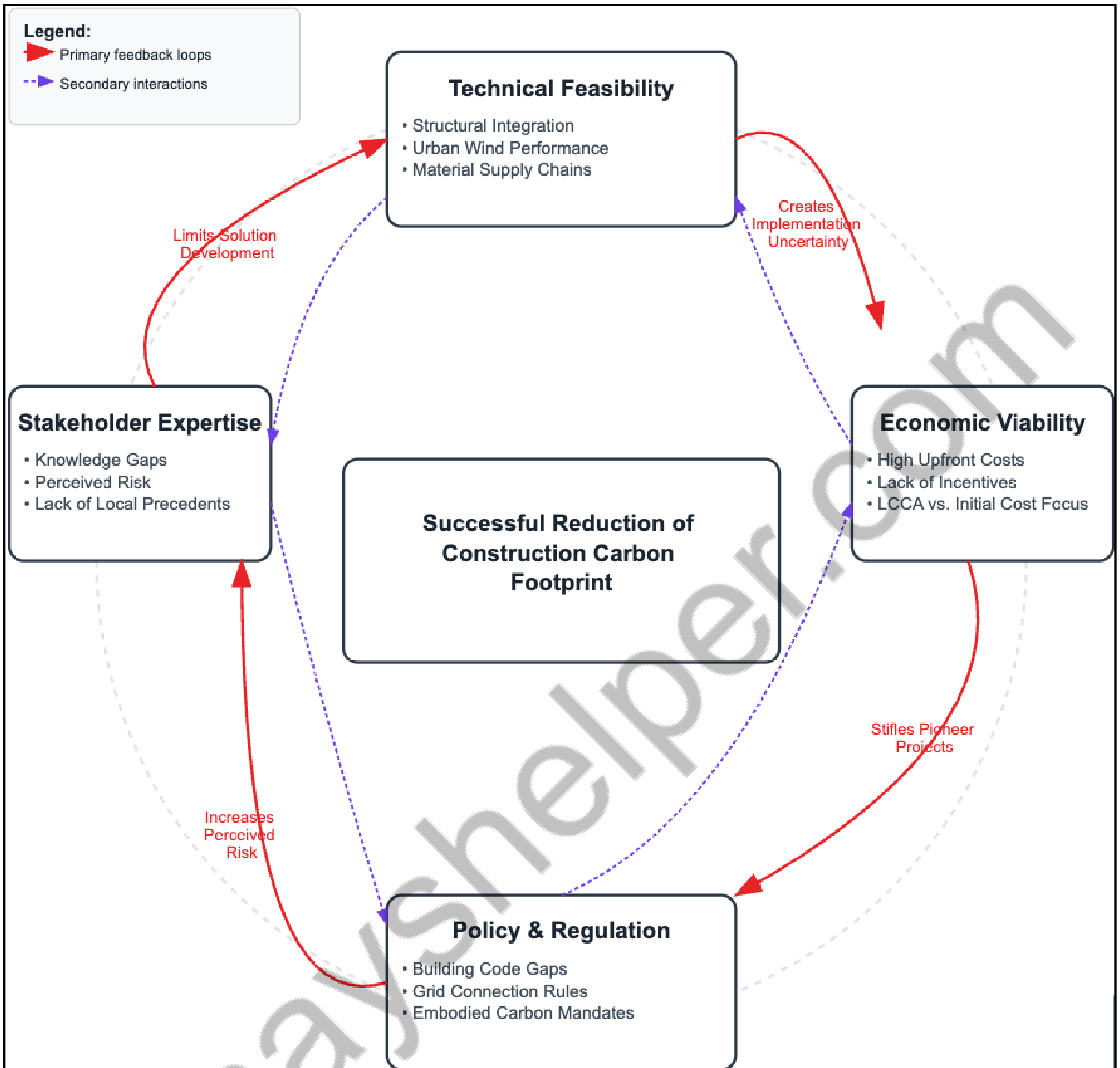

Figure 18: A Revised Conceptual Framework of Barriers

5.5 Chapter Summary

This chapter has provided a critical interpretation of the research findings, placing them in a direct dialogue with academic literature. The discussion has systematically answered the research questions, revealing that the challenges to implementing an LCA-based approach for wind energy systems in the Middle East are systemic and deeply interconnected. The findings confirm existing literature on many fronts but add crucial, context-specific nuance regarding the sources of embodied carbon, the impact of regional market drivers, and the critical role of local precedent. The theoretical and practical implications of these findings have been articulated, and a refined conceptual framework that captures the dynamic interplay of barriers has been proposed. This comprehensive discussion provides the foundation for the final chapter, which will present the study's conclusions and offer a set of actionable recommendations.

CHAPTER 6: CONCLUSION AND RECOMMENDATIONS

6.1 Introduction

This final chapter brings the dissertation to its logical conclusion. It provides a consolidated summary of the entire research journey, from the initial problem statement to the interpretation of the empirical findings. It offers a direct answer to the central research question, followed by a series of specific, actionable recommendations for key stakeholders.

6.2 Summary of Research

This study was initiated to address the critical and underexplored issue of the construction carbon footprint of commercial buildings in the Middle East, examining the potential of building-integrated wind energy systems through the lens of Life Cycle Analysis (LCA). The core problem identified was the lack of region-specific, empirically grounded understanding of the practical challenges hindering the adoption of this sustainable pathway. To investigate this, the research adopted a qualitative methodology rooted in an interpretivist philosophy. Primary data was gathered through semi-structured interviews with six senior industry professionals, including architects, engineers, and consultants, whose rich, contextual insights were systematically analysed using thematic analysis.

The research successfully met its predefined objectives. In fulfilment of Objective One, the literature review confirmed LCA as a robust framework but revealed a critical gap in its application to building-integrated wind systems and a significant lack of regional LCI data for the Middle East. The primary research directly addressed Objective Two and Objective Three, identifying the key barriers and exploring the perceptions of industry professionals. The findings were organised into four potent, interconnected themes:

1. Technical and Implementation Challenges, where structural reinforcements to manage dynamic loads were found to be a major source of "hidden" embodied carbon.
2. The Economic and Financial Landscape, which is overwhelmingly dominated by short-term CAPEX considerations, rendering long-term life cycle value arguments ineffective.

3. Policy, Regulation, and Standards, revealing a "policy vacuum" with no specific codes for turbine integration or mandates for embodied carbon assessment.
4. Professional Knowledge and Perceptions, highlighting a pervasive skills gap and a culture of risk aversion exacerbated by a lack of local case studies.

The discussion in Chapter Five synthesized these findings, concluding that the barriers form a self-reinforcing cycle of inaction that prevents widespread adoption.

6.3 Answering the Central Research Question

The central research question of this dissertation was: “How can a Life Cycle Analysis (LCA) approach inform the reduction of the construction carbon footprint of commercial buildings in the Middle East through the integration of wind energy systems?”

Based on the entire body of this research, the answer is that an LCA approach can provide critical intelligence to inform this process, but its effectiveness is severely constrained by the systemic barriers identified. It informs the process by moving beyond a simplistic focus on the turbine's operational benefits to quantify the significant, often overlooked, "upfront" embodied carbon associated with structural reinforcements and global supply chains. It provides the essential data to make truly informed decisions at the early design stages.

However, for LCA to transition from a theoretical tool to an effective instrument of change in the region, it must be embedded within a supportive ecosystem. Its insights are only valuable if they can influence design, and that influence is currently blocked by prohibitive costs, regulatory ambiguity, and a lack of professional capacity. Therefore, an LCA approach informs the process by highlighting the true carbon costs, but it cannot, by itself, drive the reduction of this footprint without parallel and fundamental changes in the region's economy, policy, and professional landscapes.

6.4 Recommendations

The findings of this study lead to a series of specific, actionable recommendations targeted at the key stakeholder groups who have the collective power to break the cycle of inaction. These recommendations, developed in fulfilment of Objective Four, are detailed below.

6.4.1 For Policymakers and Regulatory Bodies

The most powerful levers for change are systemic. Governments must create the regulatory and financial environment in which sustainable innovation can thrive. The first priority should be to mandate Whole Life Carbon (WLC) reporting for all major public and private commercial projects. This single act would immediately embed embodied carbon as a critical design metric. Secondly, they must work with industry and academia to develop and fund a regional LCI database to ensure these assessments are accurate and credible. Finally, creating targeted financial incentives, such as tax credits or grants for projects that demonstrate significant embodied carbon reductions, would help de-risk investment for developers.

6.4.2 For Industry Professionals (Architects, Engineers, Developers)

The industry must proactively build its own capacity rather than waiting for regulation. Design and engineering firms should invest in upskilling their teams through continuous professional development in LCA software and integrated design principles. Adopting a truly integrated design process, where sustainability and LCA specialists are engaged from project inception, is crucial to move beyond a compliance-based approach. Professionals should also champion the business case for low-carbon design with clients, using data to link reduced embodied carbon with long-term asset value and brand reputation.

6.4.3 For Academia and Research Institutions:

Academic institutions have a vital role in building the foundational knowledge for the industry's transition. They should integrate Whole Life Carbon and LCA principles into the core curricula of architecture and engineering programs. Furthermore, there is a pressing need for focused research on developing and documenting local, high-performance case studies and on innovating low-carbon structural solutions for technology integration.

6.5 Limitations and Suggestions for Future Research

This study's findings, while rich in detail, are subject to the inherent limitations of its qualitative design. The small, purposively selected sample means that the findings are not statistically generalizable but offer transferable insights into the perspectives of senior professionals in the region. The scope was also tightly focused on commercial buildings and wind energy and did not explore other building typologies or renewable technologies.

These limitations provide clear pathways for future research. A quantitative survey could be conducted across a much larger sample of industry professionals to test the prevalence of the barriers identified in this study. Furthermore, a longitudinal, in-depth case study of a building that successfully integrates a wind energy system in the Middle East would be invaluable for gathering real-world performance, cost, and embodied carbon data. Finally, targeted technical research is needed to develop innovative, low-carbon structural systems that can mitigate the embodied carbon penalty of turbine integration.

6.6 Concluding Remarks

The transition to a decarbonized built environment in the Middle East is a challenge of immense scale and complexity. While the barriers identified in this dissertation are significant, they are not insurmountable. They are systemic problems that require systemic solutions. Addressing the hidden challenge of carbon construction is no longer a niche concern but a central requirement for achieving the region's ambitious and necessary sustainability goals.

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Appendices

Appendix A: UWE Ethics Approval Form

The following is a representation of the completed and approved Ethics Checklist for this research project, confirming that the study is classified as low-risk and adheres to the university's ethical standards for research involving human participants.

Project Title: Assessing Environmental Performance of Wind Energy Systems in Commercial Buildings: A Life Cycle Analysis Approach to Reduce Construction Carbon Footprint in the Middle East
Supervisor Name: Adam Hill
Student Name: Wasmy Alwasmi

Summary of Ethical Review Checklist:

- **Are Human Participants involved?** Yes.
    - **Informed Consent:** Participants will be clearly asked to give consent and informed about how their data will be used via an information sheet and consent form.
    - **Right to Withdraw:** Participants will be informed of their right to withdraw at any time prior to the point of data anonymization.
    - **Confidentiality:** Measures are in place to ensure confidentiality. Data will be anonymized, and all identifiable information will be removed from the final report. Audio recordings will be deleted after transcription.
- **Does the research involve potentially vulnerable groups?** No.
    - **Explanation:** Participants are adult professionals not belonging to any vulnerable group.
- **Does the research involve intrusive interventions, deception, or sensitive topics?** No.

- **Explanation:** The research focuses on professional experiences and technical approaches and does not involve any sensitive personal matters. Interviews will be conducted professionally and respectfully.

- **Ethical Approval Status: Low Risk**.
    - **Outcome:** No further approval is needed from the Faculty Research Ethics Committee (FREC). Approval is provided by the supervisor based on the submitted Participant Information Sheet, Consent Forms, and measures for secure data management.

Appendix B: Participant Information Sheet

The following text was provided to all potential participants via email prior to their agreement to be interviewed.

Guidance on drafting a research Participant Information Sheet

Study Title: Assessing Environmental Performance of Wind Energy Systems in Commercial Buildings: A Life Cycle Analysis Approach to Reduce Construction Carbon Footprint in the Middle East

Invitation

You are invited to take part in research taking place at the University of the West of England, Bristol. Before you decide whether to take part, it is important for you to understand why the study is being done and what it will involve. Please read the following information carefully, and if you have any queries or would like more information, please contact the researcher.

Researcher Contact Details:

Eng. Wasmy Alwasmi
Email: Wasmy2.Alwasmi@live.uwe.ac.uk
University of the West of England, Bristol

What is the aim of the research?

This research project aims to explore the different challenges that project management teams face while devising and implementing wind energy systems in commercial buildings in the Middle East. The study specifically seeks to understand the challenges related to reducing the construction carbon footprint using a Life Cycle Analysis (LCA) approach.

Why have I been invited to take part?

You have been invited because your professional expertise as an architect, engineer, or consultant in the commercial building sector in the Middle East makes your insights highly relevant and valuable to this research topic.

Do I have to take part?

Your participation in this study is entirely voluntary. If you decide to take part, you will be given a copy of this information sheet to keep and will be asked to sign a consent form. You are free to withdraw from the research at any time before your data is anonymized (approximately two months from the date of the interview) without giving a reason.

What will happen to me if I take part?

If you agree to participate, you will be asked to take part in an online interview that will last approximately 45-60 minutes. The interview will be audio-recorded for transcription purposes. After transcription, the audio recording will be permanently deleted, and your data will be fully anonymized.

What are the possible risks and benefits of taking part?

We do not foresee any significant risks. If you feel uncomfortable at any time, you can stop the interview. The benefit of taking part is contributing to valuable academic research that aims to improve sustainable construction practices in the Middle East.

What will happen to your information?

All information you provide will be kept strictly confidential and anonymized. The anonymized research material will be saved on a password-protected computer for five years, accessible only to the researcher, in accordance with the Data Protection Act 2018 and GDPR requirements.

Who has ethically approved this research?

This project has been reviewed and approved by the Faculty of Environment and Technology

Research Ethics Committee at the University of the West of England. Any comments or complaints about the ethical conduct of this study can be addressed to: Researchethics@uwe.ac.uk.

Appendix C: Consent Form

The following is the text of the consent form that all participants were required to review and agree to before the interview commenced. An electronic signature or email confirmation of agreement was accepted.

Consent Form

Project Title: Assessing Environmental Performance of Wind Energy Systems in Commercial Buildings: A Life Cycle Analysis Approach to Reduce Construction Carbon Footprint in the Middle East

Please read the following statements. Your agreement confirms that you consent to participate in this research.

- I confirm that I have read and understood the Participant Information Sheet for the above study.
- I have had the opportunity to ask questions about the study and have had them answered satisfactorily.
- I understand that my participation is voluntary and that I am free to withdraw at any time before the data has been anonymized, without giving a reason.
- I agree that my anonymized quotes may be used in the final report and any subsequent publications.
- I agree for the interview to be audio-recorded, on the understanding that the recording will be deleted upon transcription.
- I agree to take part in the above research study.

Name of Participant (Printed): _______________________________

Signature: _______________________________

Date: _______________________________

Appendix D: Semi-Structured Interview Guide/Protocol

This guide was used to provide structure and consistency across all interviews while allowing for flexibility and probing of emergent themes.

Introduction

- Thank the participant for their time.
- Briefly re-introduce myself and the research topic.
- Confirm they have read the Information Sheet and have signed the Consent Form.
- Reiterate that the interview is confidential and their identity will be anonymized.
- Ask for explicit permission to start the audio recording.
- Explain the structure: The conversation will cover four main areas – technical challenges, economic factors, policy, and professional knowledge.

Section 1: Background and General Context

1. Could you start by telling me a bit about your professional role and your experience with commercial building projects in the Middle East?
2. From your perspective, how prominent is the topic of sustainability, and specifically carbon reduction, in the design conversations you are part of today?
3. Have you had any direct or indirect experience with projects considering or implementing building-integrated renewable energy, such as wind turbines?

Section 2: Technical Challenges & LCA Application (Theme 1)

4. When you think about integrating a wind turbine onto a commercial building, what are the first technical or engineering challenges that come to mind?

5. Could you walk me through how the structural design process might change to accommodate such a system? What are the key considerations?
6. From your experience, how reliable is the energy performance of these systems in a dense urban environment like Dubai or Riyadh?
7. What has been your experience with the digital workflow? How easy or difficult is it to integrate data from a BIM model into an LCA or energy analysis tool?

Section 3: Economic & Financial Drivers (Theme 2) :

8. In your experience, how do clients and developers typically react to the high upfront capital costs associated with technologies like this?
9. How effective are arguments based on long-term value, such as Life Cycle Costing or operational energy savings, in convincing a client to invest?
10. What role, if any, do you see for government financial incentives, like subsidies or tax credits, in making these projects more viable?

Section 4: Policy & Regulatory Landscape (Theme 3) :

11. Could you describe the current regulatory process for getting a non-standard system like a building-integrated turbine approved?
12. Are there clear and specific building codes or standards in the region that guide your work in this area? If not, how do you navigate that uncertainty?
13. In your view, what is the current policy stance on *embodied carbon*? Is it a metric that regulators are actively looking at?

Section 5: Professional Knowledge & Perceptions (Theme 4)

14. How would you describe the general level of expertise and awareness regarding LCA and whole-life carbon within design teams in the region?
15. What are the common perceptions of building-integrated wind energy among your peers and clients? Is it seen as a serious technology or more of a "gimmick"?
16. How important do you think local, well-documented case studies are for encouraging the adoption of new sustainable technologies?
17.

Conclusion

- Is there anything else you think is important on this topic that we haven't discussed?
- Thank the participant sincerely for their time and valuable insights.
- Reiterate confidentiality and the next steps.
- Ask if they would like a summary of the final research findings.
- Stop the recording.

Appendix E: Coded Interview Transcript (Anonymized)

Interviewee: P2 (Structural Engineer)
Interviewer: Wasmy Alwasmi (Researcher)
Date: 20 August 2025
Duration: 40 minutes
Method: Microsoft Teams (Audio Recorded)

Wasmy: Thank you again for your time, P2. I really appreciate you making yourself available. Just to confirm before we begin, you've had a chance to look at the information sheet and you're happy for me to record our conversation today?

P2: Yes, I have. And yes, that's fine. Go ahead.

Wasmy: Great. So, just to start, you have extensive experience in structural engineering in the region. When I mention integrating a wind turbine onto a commercial high-rise, what are the first technical challenges that spring to your mind?

P2: The very first thing, before anything else, is dynamics. It's not the static weight that's the issue; it's the constant vibration and fatigue from the turbine's operation, especially in gusty conditions. That's what introduces a whole new level of complexity and risk to the structural design that clients and even many architects simply do not appreciate at the outset. They just see a turbine; I see a massive, oscillating load at the top of a very tall lever arm. It's a completely different engineering problem than just adding dead weight.

Wasmy: That's a powerful image. Could you elaborate on how that complexity translates into the actual structure? What physically has to change in the design to accommodate that oscillating load?

P2: Well, everything has to be stiffer and stronger. Your building's core needs to be stronger, your connections between beams and columns more robust, and you often need to add dedicated damping systems. You're adding significant mass to the structure just to dampen the vibrations and manage the fatigue stresses over the life of the building. In simple terms, you are adding a lot more concrete and a lot more steel than you otherwise would have. And right there, your embodied carbon calculation, if you're even doing one, has gone through the roof before you've even considered the carbon footprint of the turbine itself.

Wasmy: So the solution to the technical problem directly creates a carbon problem.

P2: Exactly. It's a paradox. You're adding tons of upfront embodied carbon to save what might be a trickle of operational carbon. The maths often doesn't work out, especially when you consider the real-world performance of these turbines in a city like Riyadh or Dubai. Investors are wary of unproven tech in this market.

Wasmy: Let's talk about that performance. How confident are you in the energy yield predictions you typically see for these urban systems?

P2: (Sighs) Not very. The wind here is not like it is offshore or in an open field. It's turbulent, it swirls around buildings, it creates eddies and downdrafts. An anemometer on a pole on the ground tells you nothing about the chaotic conditions 200 metres up, right next to another tower that's interfering with the airflow. I've seen glossy reports from manufacturers promising great numbers, but I am deeply sceptical about what they can actually deliver consistently over a 20-year lifespan. It's a very difficult thing to model accurately.

Wasmy: Moving to the economic side of things, how does this technical uncertainty and the clear need for extra structure play out in conversations with the developer or the client?

P2: It's a very short conversation. Honestly. The developer and their project manager see two things: a higher upfront cost for the structure, which is a hard, non-negotiable number, and a risky, uncertain return on the energy side, which is a projection. There's a risk premium. Insurers, financiers, they all get nervous about an unproven system. That adds indirect costs and headaches to the project that are hard to quantify but very real. The project's financial viability is almost always killed right there. It very rarely gets past a concept or feasibility stage.

Wasmy: Is the concept of long-term Life Cycle Costing ever a persuasive argument in those meetings?

P2: Rarely. The dominant model in this region, for commercial development, is often to build and sell, or build and lease with a view to selling. The developer who pays for the extra steel and the expensive turbine is not the one who will be saving on the electricity bills in 15 or 20 years. It's a classic split incentive. Unless the system adds a quantifiable premium to the rental income or the final sale price of the building, it's just a cost with no return for them. They are focused on their exit strategy.

Wasmy: That makes sense. What about the role of policy in all this? Are there standards or building codes that help you navigate the technical challenges you mentioned?

P2: That's the other major headache. There are no dedicated codes for dynamic loads on building facades' s. I have clear, prescriptive codes for seismic design, for fire safety, for wind loading on the building envelope, for literally every other major component. For wind turbine integration and its specific dynamic effects? Nothing. We are forced to extrapolate from standards meant for ground-based structures or from other industries, which is a grey area legally and technically. It puts all the liability squarely on the design consultant.

Wasmy: And what about embodied carbon itself? Is that on the regulator's radar in your experience?

P2: Not in any meaningful way. The green building codes here, like Mostadam or Estidama, are still overwhelmingly focused on operational energy. They measure kilowatt-hours per square metre. They don't have mandatory targets for upfront carbon. So there's no regulatory driver forcing the client to care about the embodied carbon of the extra steel we just discussed. It's an externality that the project doesn't have to account for.

Wasmy: Finally, let’s talk about people and perceptions. How important are local examples or successful case studies when you’re trying to propose something innovative like this?

P2: Absolutely critical. It's probably the most important thing to overcome the financial and risk barriers. Don't show me a case study from a cool climate in Germany or Canada. Show me one that has been operating successfully in the Gulf for ten years. The climate, the dust, the humidity, the specific wind patterns, the maintenance challenges—it's all different here. Without local proof, it’s all theory, and no one here will invest millions of dollars based on theory. They need to see it working on their neighbour's building first.

Wasmy: That's a perfect summary of the challenge. P2, this has been incredibly insightful and has provided so much clarity. Thank you so much for sharing your expertise.

P2: You're welcome. It's an important topic. I'm glad someone is looking into it properly. Best of luck with your dissertation.

Wasmy: Thank you. I’ll stop the recording now.